P. MANGRIOTIS

Lloyd's Register Technical Association

TECHNICAL RECORDS — 1979

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TECHNICAL RECORDS — 1979

by T. SULLIVAN

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1. INTRODUCTION

1.1 Most Surveyors are aware of International Conventions Department, Hull Structures, Ship and Engine Reports, etc. but not of the existence of Technical Records Office, let alone its structure or function.

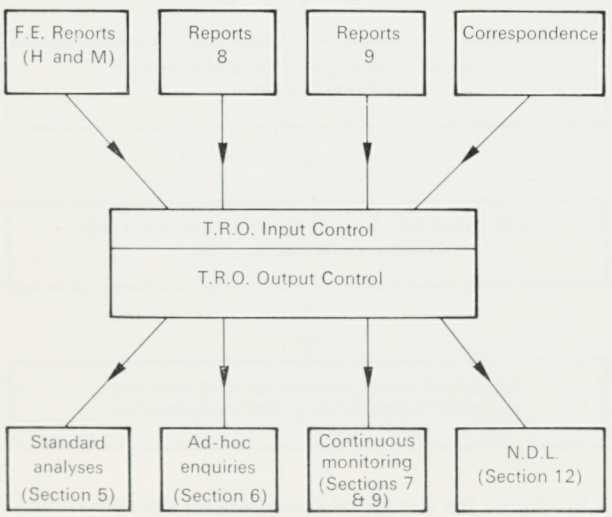
1.2 The department is still not as well known as might be wished inside Head Office, as well as outside, and this could be due, in part, to its name. The department is still occasionally confused with Records Dept., which is responsible for storing plans and reports, etc., or is thought of as the repository for large numbers of edge-punched cards containing technical data which can be extracted by the manipulation of specially designed needles. These are unfortunate facts and it is for this reason that the historical development of the department needs to be outlined in order to place its present structure and function into perspective.

1.3 The structure of the department is unlike any other in Head Office and comprises four disciplines who work together under a Senior Principal Surveyor. The four disciplines are:

Ship Surveyors
Engine Surveyors
Statisticians
Non-technical specialists.

Administrative back-up is provided by TSG/RATAS while the computer systems maintenance is provided by members of the Data Processing Department of Computer Services.

1.4 The work structure of the department is outlined in the following diagram:



1.5 The technical services which a Classification Society can offer to the industry depend almost entirely upon accumulated experience, research and judgement. The first of these, *experience*, is acquired by the Surveyors whilst carrying out surveys on every variety of vessel and embodying these experiences in their reports. The second, *research*, is carried out by the Society itself, utilising the accumulated experiences of the Surveyors, reports of research organisations, transactions of learned Societies, periodicals and books, etc.

The third, *judgement*, is a matter of opinion based on experience, but judgement without facts is, of course, guesswork. In order that the massive feedback of information on L.R. classed ships may be readily accessible for use in helping to form judgements, the first essential is that the reports should give adequate details of all defects and damages and the second is that it should be presented in a form which can easily be analysed. It was the realisation of these facts which lead to the formation of the Technical Records Office.

2. HISTORICAL BACKGROUND

2.1 It was left to the individual Surveyors in Ship and Engine Reports Departments to draw to the attention of the Chief Surveyors, any unusual items reported, particularly any important recurring defects. This was done mainly on the basis of examination of current reports without detailed reference to previous reports. Some rather incomplete notes on reports of particular types of hull and machinery defects were kept in "Heavy Weather Books". Although some cross-indexing was done in these books, it was minimal and the only reliable way to find comparable cases was to search through the books.

2.2 A study was made with the object of introducing a more effective method and in 1948 a system based on edge-punched cards was adopted for hull defects. This was extended in 1953 to cover machinery defects.

2.3 The principle of the system was that the reports were summarised and entered on standard cards which had perforations around the edges. Each hole was assigned a definite meaning, and when this meaning applied to the particular item entered on the card, the hole was notched with a punch so that it was open to the edge of the card. When the cards so punched were assembled in random order in a pack, a needle was passed through a hole position and the cards which were notched at this position were free to fall out of the pack. By this means, all the cards which had a given characteristic, or combination of characteristics, could be readily isolated. It was the first application of this system on such a large scale and naturally, a great deal of thought and effort had to be applied in selecting the meanings to be assigned to each of the holes.

2.4 It was quickly realised that the system did not contain enough "background" information to enable reliable statistics to be made, i.e. the relating of the number of defects of comparable ships at risk with the number of years service of these ships. It was therefore decided to set up a separate system, using the edge-punched cards to record the technical details of all L.R. classed ships including their machinery. This was introduced in 1958 for the machinery and in 1960 for the hull.

2.5 It had become apparent by 1963 as the demand for detailed statistics developed, that the large edge-punched cards were somewhat unwieldy to sort, handle and count. Moreover, they could not accommodate the increasing amount of technical detail which became necessary as the usage of the system increased. It was therefore decided to introduce a mechanical system for recording and retrieval.

2.6 The transfer of the whole of the department's data for the entire classed fleet, hull and machinery, defects and basic data, to 80 column punched cards which could be manipulated by an electronic sorter was commenced in 1964 and accomplished over a period of six years together with the entry into the system of current reports at the rate of approximately 400 per week. This was a great advance on the previous system but the cards still had to be handled manually. This 80 column card system required the creation of numerical codes covering the whole range of defects, their nature, cause, location and any corrective measures taken, also for identification of all items comprising the "basic" data.

2.7 With this system, a greatly increased amount of data could be stored and the process of data retrieval was speeded up.

2.8 Mechanisation of the basic data also gave birth to the L.R. identity number. This unique number is assigned to every ship built in the world and entered in the Register Book. It was devised by T.R.O. and originally consisted of six digits, which has now been increased to seven. The last figure being a check digit confirming the accuracy of the others. The L.R. number remains unchanged throughout the life of the ship and this is indispensable in the era of computer data processing, especially as most individual particulars of a ship are liable to change in its lifetime, the most common of which being its name.

2.9 When initiating the 80 column card system it was decided, for various reasons, to limit the data recorded to ships built 1960 and later and that only damages occurring during the first 25 years, and wear and tear in the first five years, of a ship's life are considered.

3. CURRENT STAGE

3.1 The current stage of the department's development utilises the resources of a computer to analyse in a variety of ways the vast amount of stored data.

3.2 1969 saw the start of discussions with Computer Department personnel, aimed at storing the data on disk in the IBM main frame computer. The programming was completed and the procedure developed by February 1973. It should be stated that a great deal of consideration, time and effort were involved based on earlier experiences and the structure of the present system has remained unchanged since, except for some minor improvements and fine tuning.

3.3 The reality of the department's services has been made possible through the development and maintenance of the computer systems by members of the Data Processing and Technical Applications sections of Computer Services Department.

3.4 The dates given above are, in the main, when the separate systems and stages were operating and do not reflect the overlap times spent in developing new methods to cope with new requests and in learning from practical usage of failings and limitations of what was currently in use.

4. COLLECTION AND CODING OF DATA

4.1 Two main groups of information are recorded on the department's database, namely, Basic data and Defect data. The latter cannot be used meaningfully on its own, whereas the former can e.g. when dealing with market research enquiries.

4.2 Basic Data

Fig. 1 gives the procedure for storage of Basic data on the Ship record.

Basic data is obtained from hull first entry reports and accompanying plans, etc. and transferred to the basic data card (Fig. 2) by Ship Reports Department. A similar operation is carried out on the machinery basic data cards (Fig. 3).

4.3 After the first entry reports have been processed by the Classing Committee, the basic data cards are checked in T.R.O., and using tables which break the structure and equipment into 400 "fields" (hull and machinery), are coded by specially trained staff. An illustration of a coding sheet

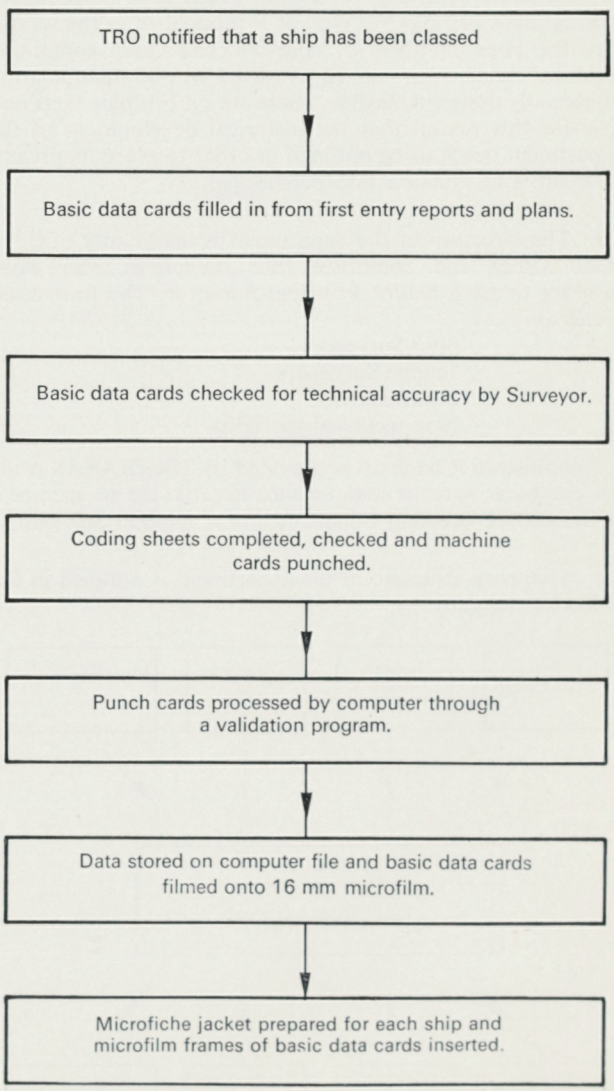
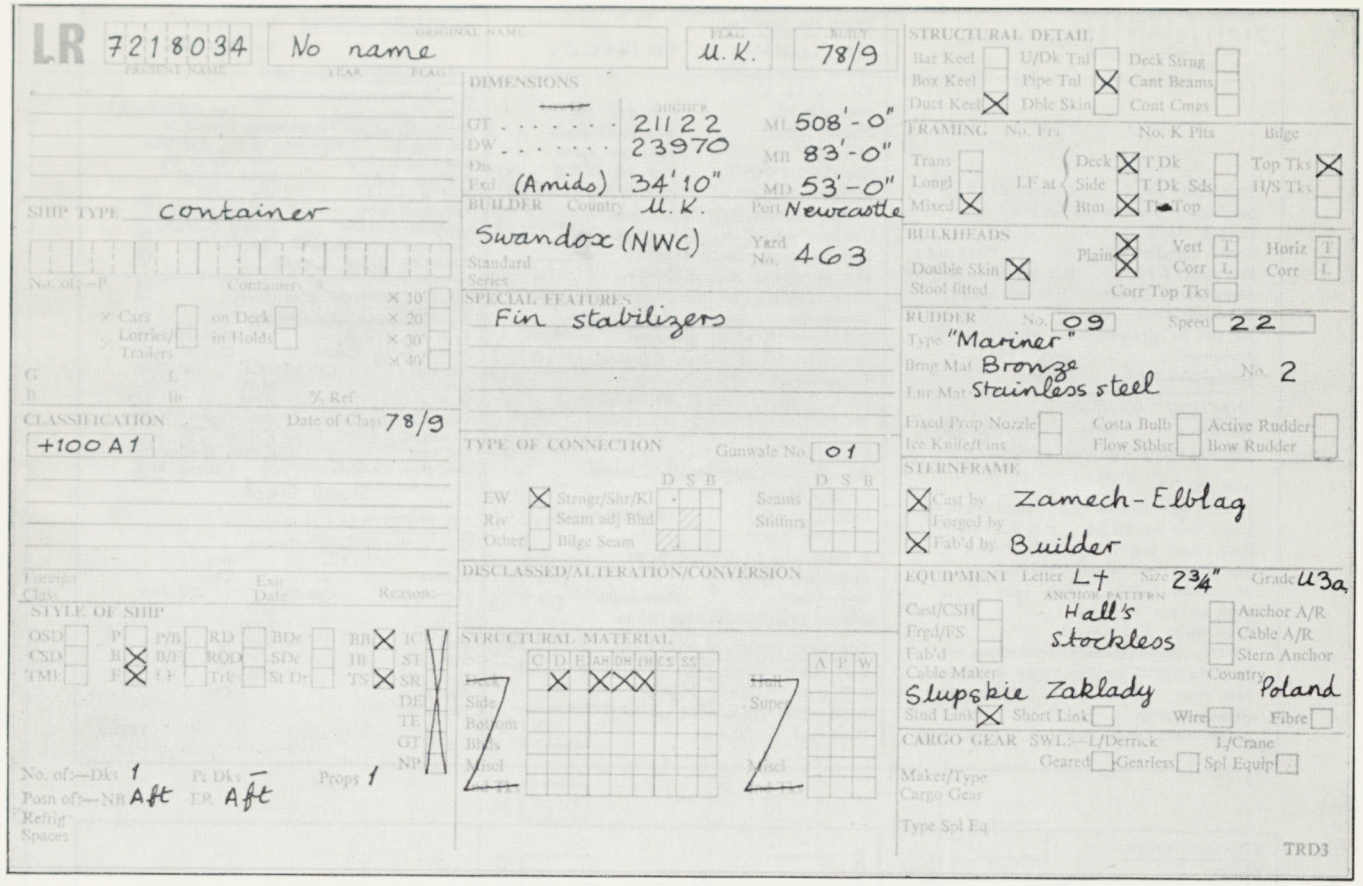


FIG. 1

Procedure for storage of Basic data on the ship record



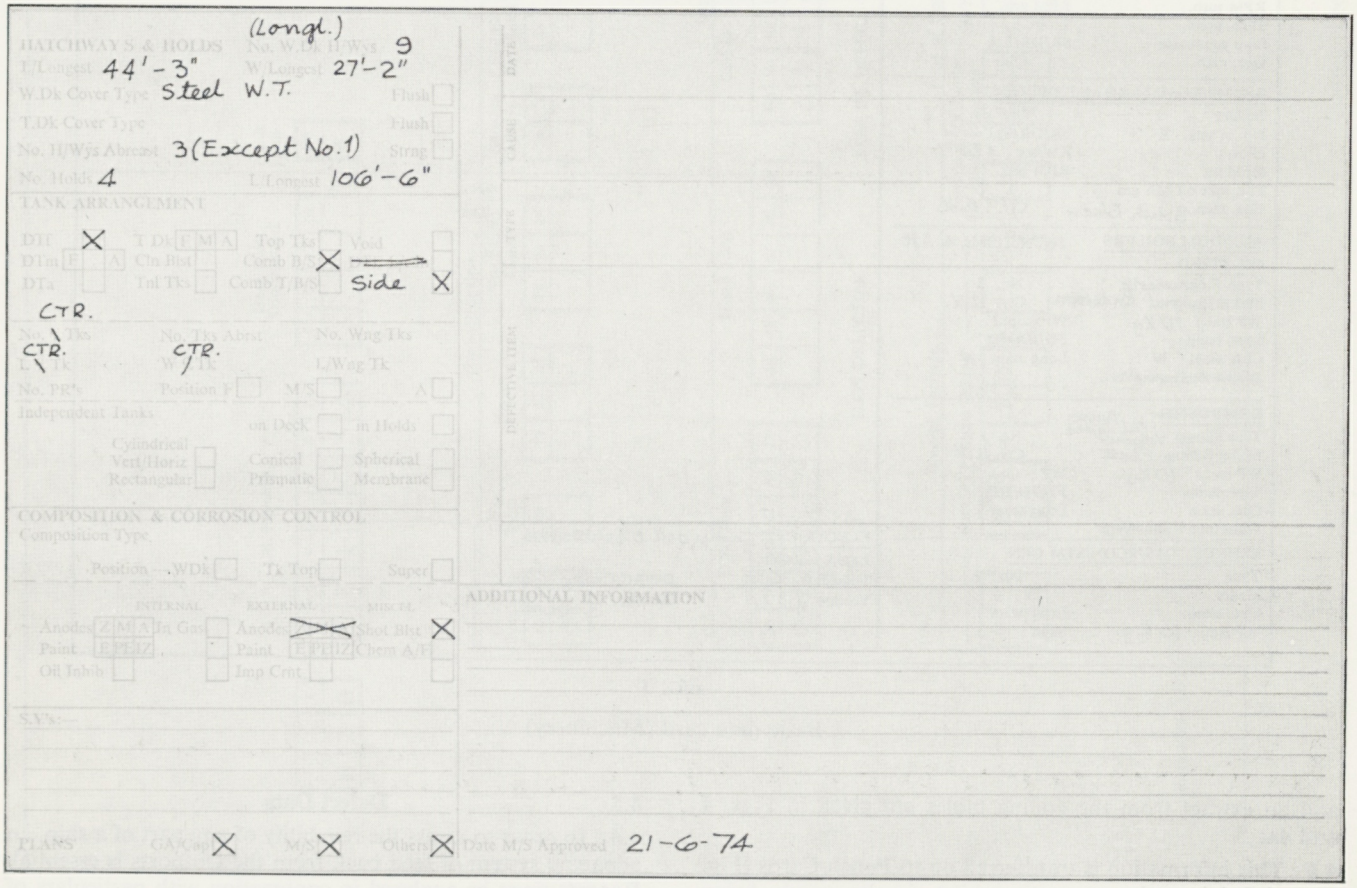


FIG. 2

Basic data card (Hull)

7 2 1 8 0 3 4 No name
Renamed

Date build 78/9 G. tons 21122
Shipbuilder Swan Hunter (NWC)
Country U.K.
Service Container UMS yes
Pos. mchy. Aft. Bas. type Oil geared
Method drive Conv. O. W. sep. yes
~~Drive spec. feat.~~
No. pps. on bilge serv. 4 Tot. SHP 16,380
~~Thrust unit~~ ~~No.~~
~~D of C after build~~ Disclass

SHAFTING 16,380
No. screws 1 HP/shaft RPM 140
~~CT~~/OG/~~Other~~ Deep sea seals
Mat. TS. F.C. solid
Holl TS yes Holl IS yes Short s'bush yes
Len. s'bush. brg. 1524 mm Dia TS 620 mm
Spec. s'bush. brg. Turnbull mk 1
Mat. s'bush. brg. white metal
Mat. s'tube. Steel Fab. yes
Prop. seal arr. O.G.
Prop. design Kamewa
CP Prop./~~Built-up/Solid/K. nozzle/Cont. rot.~~
Prop. dia 5105 mm No. blades 4 Keyless
Mat. prop. Novoston
~~Mat. spare prop.~~
Means attach. Flange IN

MAIN OIL ENGINE
Type Pielstick Des. 18PC2V
Builder Crossley
Country U.K.
Engs./ship 2 Cyls./eng. 18
~~Xhead~~ or trunk ~~Opp. pis./T. bank~~
~~2SA~~/4 SA Vee angle yes
Size 400 x 460 MIP 16.5 kg
BHP/eng. 8190 RPM 450
No. exh. blowers 2 No. mech blowers 0
S'charged yes Pis. cool. Oil
Mat. cyl. covers Cast iron
Mat. pis. crowns al. alloys
Welded bedplate yes frames yes entab. yes
~~Revers. eng.~~ Hvy. oil yes
C'shaft type Solid forged
Damp/Det. type Spring sleeve
~~Barred speeds~~
No. L. O. cools (Main) 2 No. air comps. 2
No. F. W. cools (Main) 2 No. air recrs. 1 Repair spares

GEARING
Manufacturer Cammell Laird
Country U.K.
Design SR/~~DR/Rev./Epi.~~
Flex coup. manuf.
F. coup. man. des. Geislinger Fawick clutches (air)
Coup. type Spring
~~2 speed box~~ ~~Lwr. RPM~~
~~Step up + V. Schn./V. Schn.~~/Schott.

STEERING GEAR and WINDLASS
S. G. maker. Hastie
S. G. type. Elect. Hyd.
Wind. maker. Clarke Chapman
Wind. type. Elec.

AUXILIARY ENGINES Tot. dies cards.
Tot. other cards.

OIL ENGINES (of same type)
~~Gen./T. Winch/Harbour/Emerg.~~
Type Paxman Des. 8RPHXZ
Builder Ruston Paxman Cty. U.K.
No. engs 2 Cyls./eng. 8 ~~2SA~~/4SA
Size 178 x 197 MIP. 10.5 kg
BHP/set 422 RPM 1200
Fuel diesel Vee 60°
S'charged yes KW/set 290
Cyl. cool water C'shaft Solid
Gen. man. Brush Elec. Cty. U.K.
Pos. in e.r. fwd – aft

OIL ENGINES (diff. from above)
Gen./~~T. Winch/Harbour~~/Emerg.
Type Eng. Elec. Des. GLD 11
Builder Eng. Elec. Cty. U.K.
No. engs 1 Cyls./eng. 6 ~~2SA~~/4SA
Size MIP.
BHP/set RPM
Fuel Vee yes
S'charged KW/set 75
Cyl. cool C'shaft Solid
Gen. man. G.E.C. Cty. U.K.
Pos. in e.r. Boat Deck

OIL ENGINES (diff. from above)
Gen./T. Winch/Harbour/Emerg.
Type Des.
Builder Cty.
No. engs. Cyls./eng. 2SA/4SA
Size MIP.
BHP/set RPM
Fuel Vee
S'charged KW/ set
Cyl. cool C'shaft
Gen. man. Cty.
Pos. in e.r.

TRD/1

STEAM TURBINE
Builder Cty.
No. of sets Design
SHP/set KW/set
RPM turb. RPM gen.
Turb. press. Temp.
Own condenser SR/DR/Epi
Gen. man. Cty.

~~S. RECIP/GAS TURB~~ M. E. DRIVEN
Builder Cty.
No. of sets 2 SR/DR/Epi
HP/set KW/set 480
RPM set RPM gen
Pos. take off ME gen.
Gen. man. Brush Elec. Cty. U.K.

AUX/DOM BOILERS Tot. No. cards. 4 Aft
OIL FIRED
Type Flemming No. 1
Maker Marshal Anderson Cty. U.K.
WP (sat.) 10 Kg WP (supt.)
Supt. temp. FD/~~ID/ND~~
Circ. seam W Long seam W
~~Watertube Horiz.~~/Vert.

~~COMPOSITE~~ Aux Oil fired
Type Stone Vapour No. 1
Maker Stone Platt Cty. U.K.
WP (sat.) 10 Kg. WP (supt.)
~~Supt. temp.~~ FD/~~ID/ND~~
Circ. seam Long seam
Watertube ~~Horiz./Vert.~~

EXHAUST GAS/ECON/STM GEN
Type No. 2
Maker
Circ. seam Long seam
WP (sat) 10 Kg. Supt.

DATE

TYPE OF DEFECT

ITEM DEFECTIVE

ELECTRICAL Campbell & Isherwood
Equip. installer
Total KW 1615 ~~Def~~AC/Cyc/sec. 60
Voltage 440 Distribn. 3 wire

FIG. 3

Basic data card (Machinery)

and an extract from the coding tables are given in Figs. 4 and 4A.

4.4 This information is transferred on to Punch Cards (Fig. 5) and fed into the computer whilst simultaneously being subjected to a Validation check. Example of validation check is shown in Fig. 6.

4.5 **Defect Data**

4.6 In order to assess the reliability of any part of a ship, an adequate system of feed back from the Outports is essential. Reports must be analysed in conjunction with particulars of the numbers at risk, their time in service and their varying conditions of usage in order to establish the areas prone to

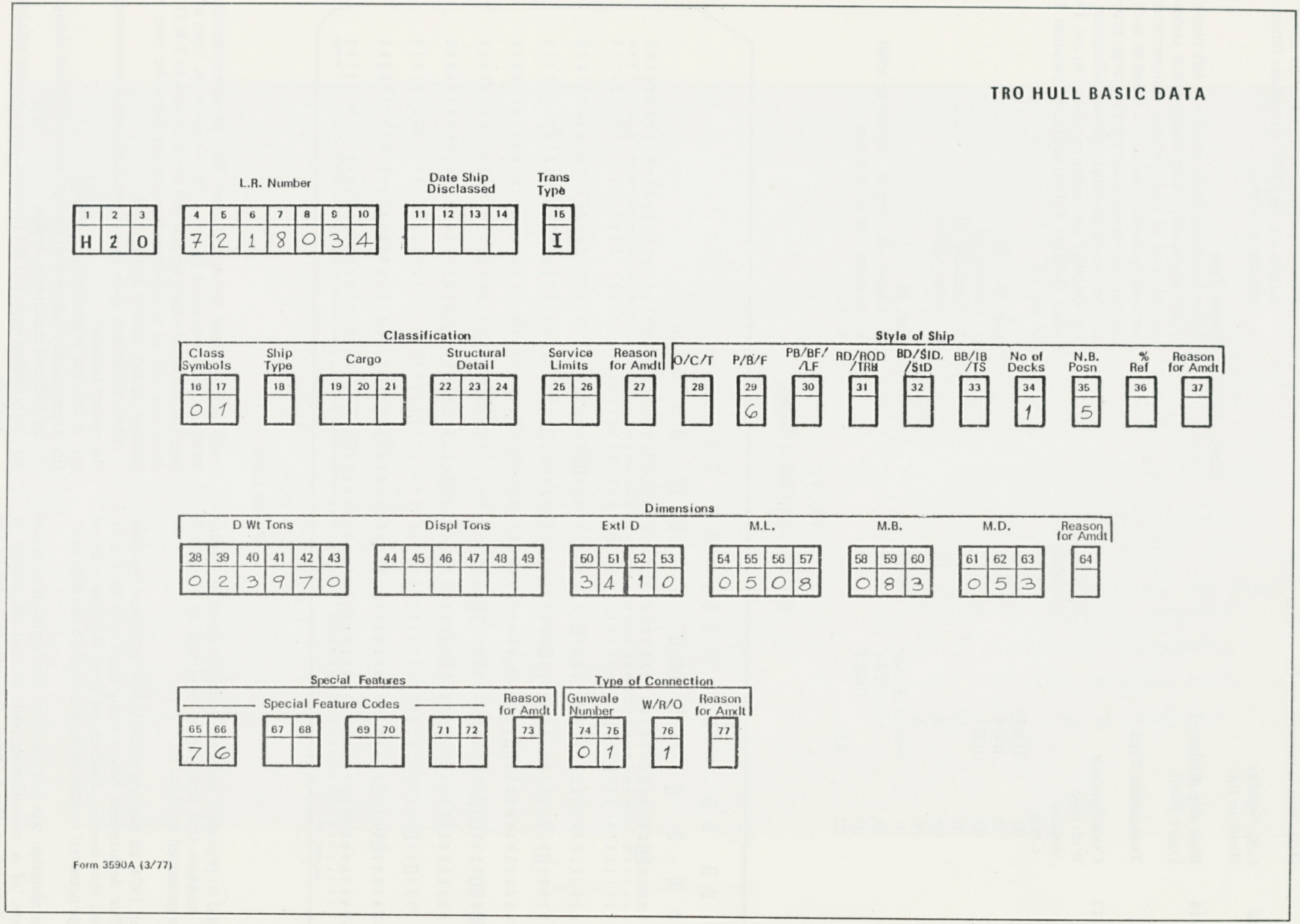


FIG. 4

Coding sheet (Hull)

Hull Basic Data (3 cards—H20, H21 and H22)

Cols. 1–3 **File Identity**
H20. This is printed on the coding sheet

Cols. 4–10 **L.R. Number**
Write in full

Cols. 11–14 **Date ship disclassed**
Leave blank

Col. 15 **Transaction Type**

Cols. 16–17 **Class Symbols**

With (✠) *Maltese Cross*		Without *Maltese Cross*
01	100A1	11
02	100A–	12
03	100A	13
04	A1	14
05	A–	15
06	A	16
07	Wood classes	17
08	OU100A1	18
09	100AT	19
22	AN	

Col. 18 **Ship type**
1. When ship type is specified in the classification e.g. ✠100A1 oil tanker. Otherwise leave blank

Cols. 19–21 **Cargo Type**
Three 1-column fields which are left blank if not applicable. Also combination codes can be used in each column. Information concerning cargo type can be found in each column. Information concerning cargo type can be found in some ship classifications, e.g. ✠100A1 Oil tanker becomes 1 in col. 19 while ✠100A1 DTsA edible oil becomes 2 in col. 19.

Col. 19
1 mineral oil
2 vegetable oil
4 other liquids

Col. 20
1 Chemicals—liquid, molten or solid
2 Asphalt, tar or bitumen
4 Ore

FIG. 4A

Extract from Coding Tables

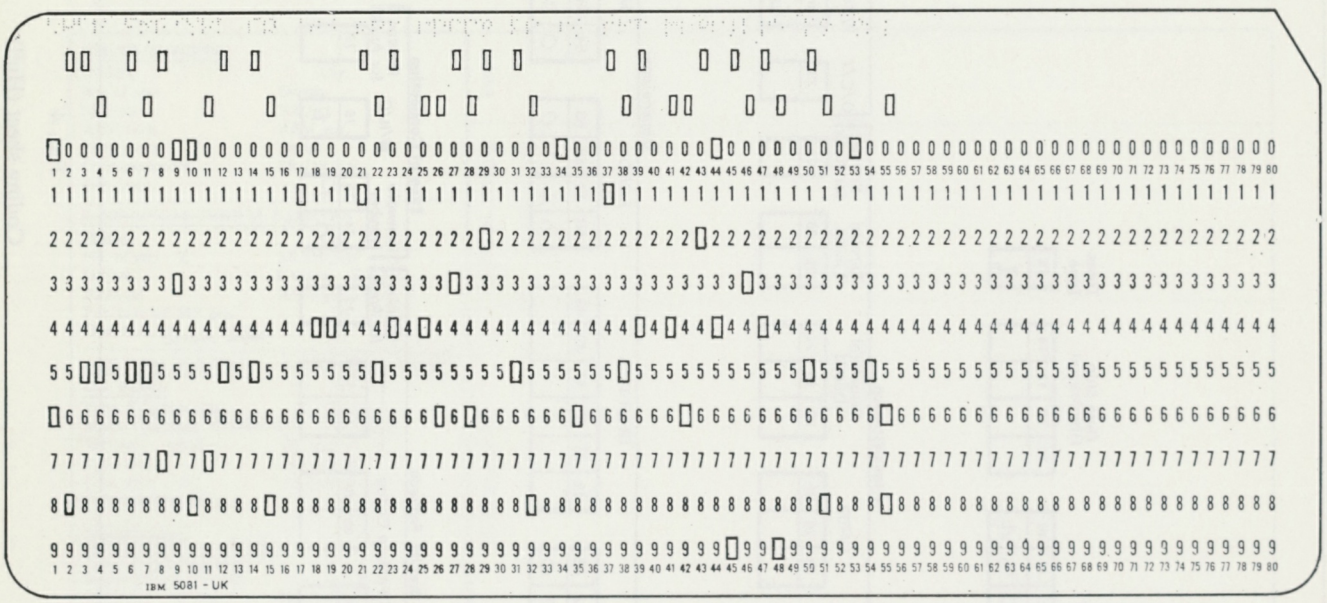


FIG. 5

Punch Card

trouble and so provide a basis for research aimed at eliminating the problem. It is with this in mind that all Reports 8 and 9 are processed by T.R.O.

4.7 Until 1974, all Reports 8 and 9 were processed by other Head Office departments before being dealt with by T.R.O. This meant that months could elapse from the time a defect or damage occurred to same being recorded on the data base.

4.8 This situation was improved by the installation in the department of a microfilming unit, so that on receipt of Reports 8 and 9 in Head Office, they are first sent to the Computer Department for punching items such as CSH and CSM and then sent to T.R.O. where those relating to ships built 1960 and later are microfilmed. But, as approximately 1000 reports are received in Head Office each week from all over the world, of which around 400 are dealt with in T.R.O., there can still be a considerable time-lag from the time a damage occurs until it is recorded.

1960 was decided upon as a convenient date to commence the system because:
(a) It was the beginning of a decade.
(b) It coincided roughly with the first major post-war change in hull and machinery design.
(c) Information back to 1960 provided a nucleus for reliable analysis.
(d) It was expedient to have a cut-off at this date due to the sheer volume of coding involved.

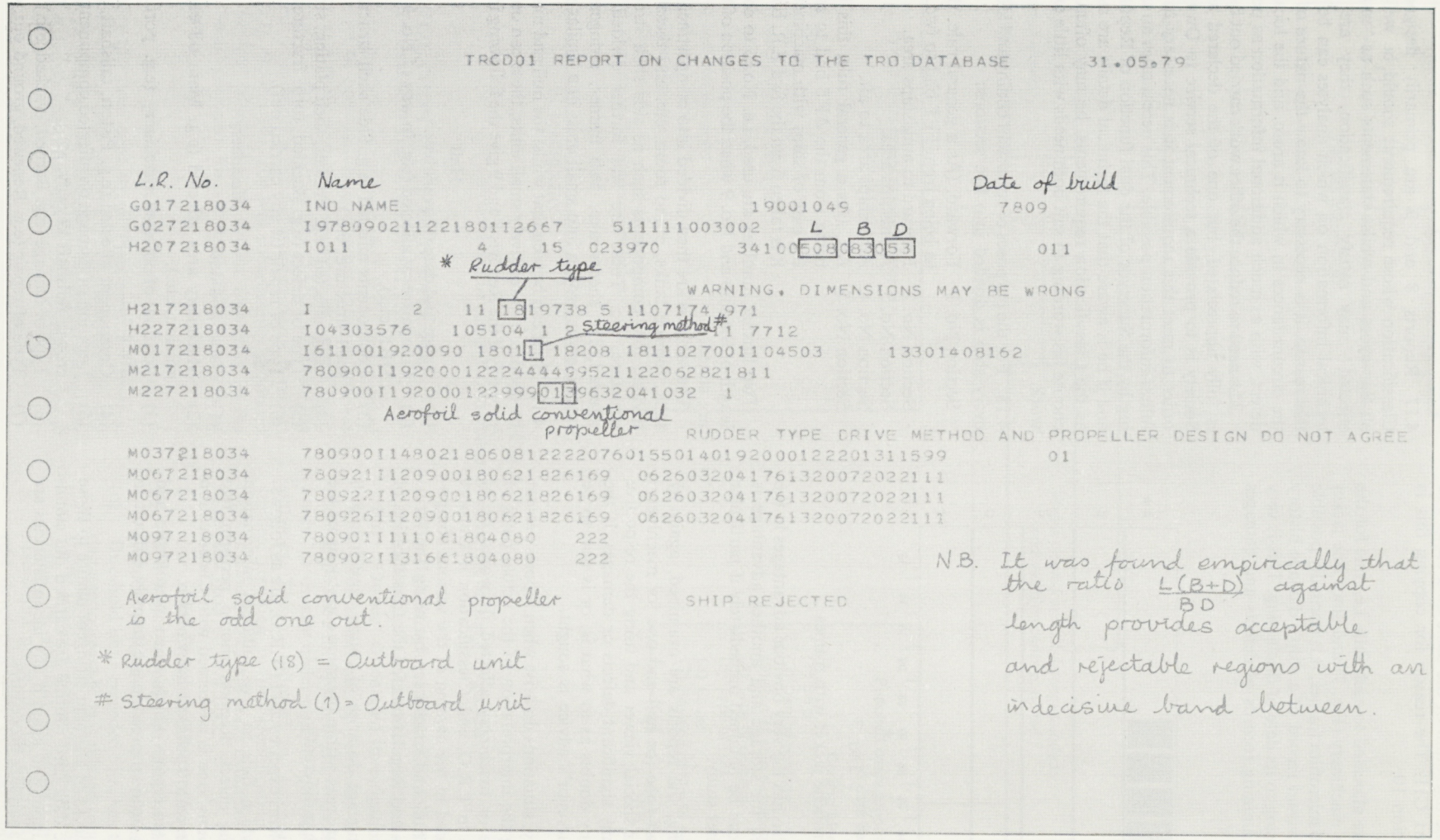


FIG. 6

Example of validation check

4.9 After processing, the microfilm frames are inserted into their relevant microfiche jackets (Fig. 1) identified by the L.R. number, alongside the microfilm of the basic data cards and sketch of the Report C11. The reason for copying this is explained under section 10.

4.10 Two jackets are allocated to each ship, i.e., one for the hull and one for the machinery (Fig. 7) and since one jacket will accommodate 60 microfilm frames, it is normally possible to have a complete visual record of a ship's damage history from its date of classing to its date of disclassing. This is very convenient when examining records of defects and damages on individual ships.

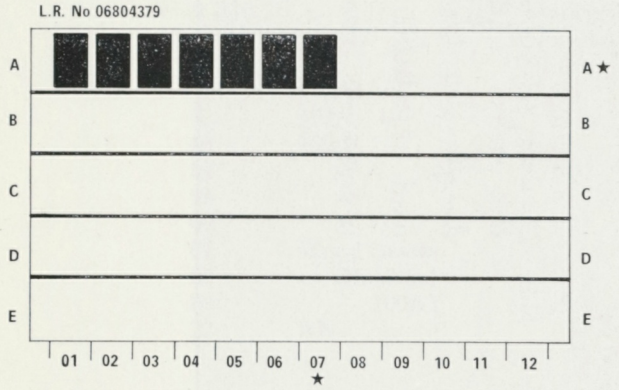


FIG. 7

Microfiche jacket with frames

4.11 The system also has the very obvious advantages in the small space required for storage and another advantage is that A4 size prints can be obtained immediately if particular reports require further study.

4.12 After jacketing, the reports are examined, again by specially trained staff (one for hull and one for machinery) who by means of a special viewer and using the respective code books, code any significant defects or damages. If the coding staff have any doubts as to what is, or is not, to be coded, a Senior Surveyor's advice is sought.

4.13 Unfortunately, situations do arise when reports present problems regarding the interpretation of the actual parts of the ship's structure or machinery affected. It would be of immense assistance to T.R.O. and Classification if Outport Surveyors were guided in the naming of the various component parts of the hull and machinery by using the terms quoted in the Rules and Regulations for the Classification of Ships.

Difficulties of language do arise of course, and it is well known that different areas within the same country name the same part of the ship differently.

4.14 Further problems experienced in T.R.O. are as follows:

(a) The report which fails to give sufficient information concerning the defect. Reports should perform two distinct functions, one is concerned with Classification and the other with Technical information.

(b) The handwritten reports which, when microfilmed and viewed on an opaque screen, are extremely difficult to read.

4.15 Validation checks of a similar stringent nature to those applied to the basic data card routine are carried out simultaneously with the input and again if any inconsistencies are highlighted during analysing procedures.

4.16 It should be pointed out that whilst it is realised that the information received does include inconsistencies and errors, it is on the whole, sufficiently accurate to be used statistically. The extent of these inconsistencies and errors should, however, be kept to a minimum.

4.17 Reports 8 and 9 are primarily designed around Classification whose requirements should be well known to all Surveyors and whilst statements such as "minor repairs effected" may satisfy classification, they are useless as technical information on which analyses can be based. For this reason, it is necessary to know the nature of the defect, the circumstances in which it arose, and the location of the defect, with as much additional information as possible.

The need to reduce the office work carried out by Surveyors is fully appreciated, but one of the declared aims of the Society is to provide a technical service to Owners, and in order to meet this requirement it is necessary to report the fullest information possible. This necessitates an understanding by the Surveyor of the dual function of Reports 8 and 9, and if he is aware that the technical details are as important as the Classification requirements, he may often be able to choose his wording to suit both needs with little extra clerical work.

4.18 For the purposes of consistent coding and identification, every ship is divided into five sections:

Section No. 1	Forward. (As a general rule, this is taken as being from FPT bhd to fwd.)
Section No. 2	Forward to amidships area.
Section No. 3	Amidships area.
Section No. 4	Amidships area to aft.
Section No. 5	Aft. (As a general rule, this is taken as being from the APT bhd to aft except in the case of ships with machinery aft when it is taken from the fwd E.R. bhd to aft.)

Two further numbers are used, i.e. No. 6 to cover the full length of the ship and No. 9 when the position of the defect is not stated.

The sections are then divided into compartments, e.g. F.P. tank, topside tanks, pump room, etc. and these are further divided into components such as side shell structure, D.B. structure, etc. These are still further divided into items affected, i.e. sheerstrake, web frames, stringers, etc. The machinery is broken into small units in a similar manner.

4.19 So it can be seen that whilst the hull and machinery can be divided into relatively small units, these can only be coded properly if the Reports 8 and 9 give the following information:

Hull

(1) Cause and date (if available).
(2) Compartment affected (e.g. In way of No. 1 hold, No. 1 DBT, etc.).
(3) Components affected (e.g. Side shell structure, bottom shell structure, etc.).
(4) Items affected (e.g. Frames, shell plating, stringer, etc.).
(5) Type of defect (e.g. Buckled, torn, fractured, etc.).
(6) Type of repair (if any carried out).

Machinery

(1) Cause and date.
(2) Machinery area affected (e.g. Main oil engine, transmission, etc.).
(3) Position of affected machinery (e.g. port, starboard, aft, etc.).
(4) Component affected (e.g. Piston, tailshaft, etc.).
(5) Location of damage on affected component (e.g. Piston crown, tailshaft keyway, etc.).
(6) Type of damage (e.g. Burned, cracked, etc.).
(7) Type of repair (e.g. Renewed, ground out, etc.).

4.20 Fig. 8 gives the procedure for storage of damage information on the ship record.

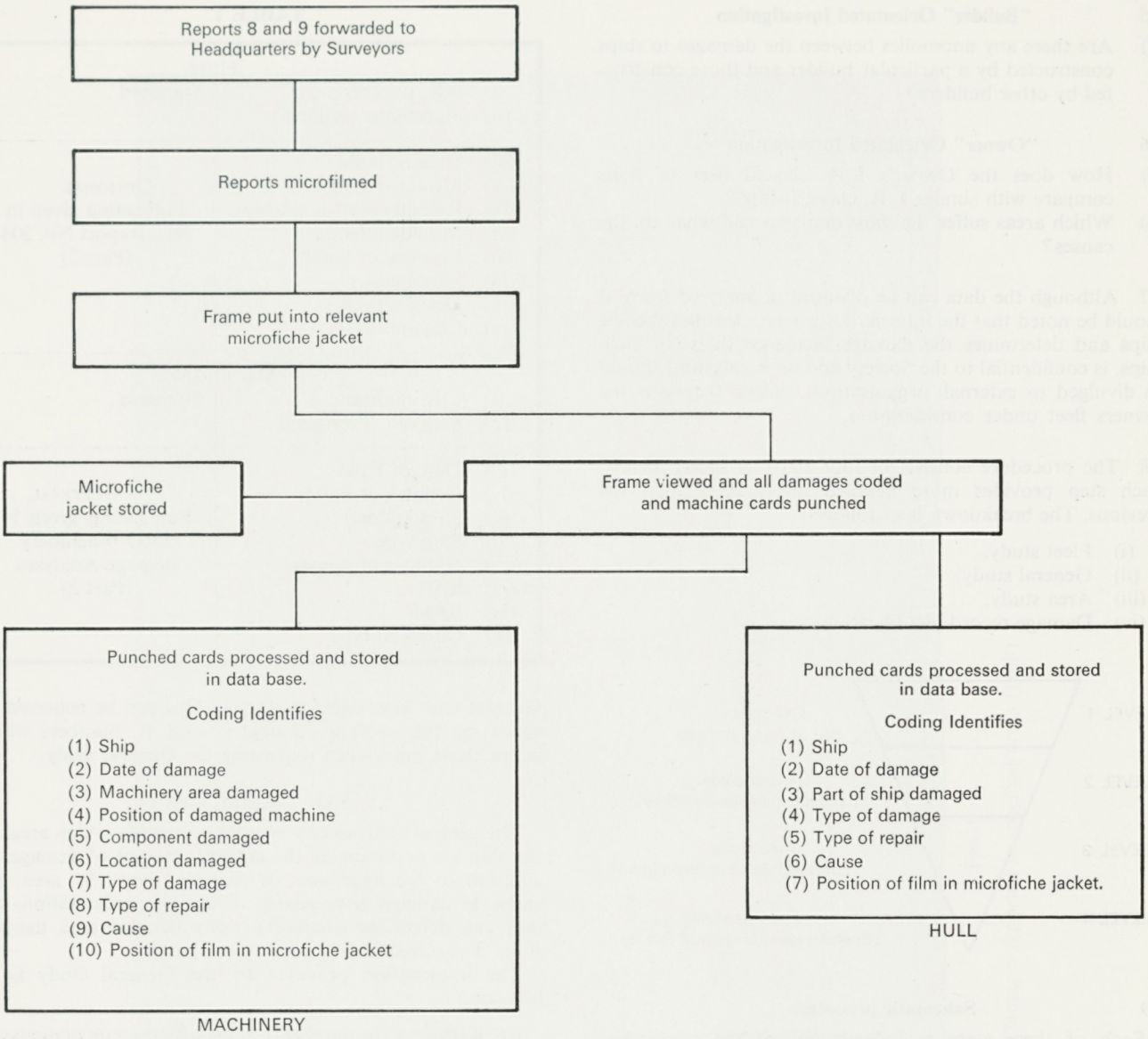


FIG. 8

Procedure for storage of damage information on the ship record

5. APPLICATION OF STORED DATA FOR STANDARD DAMAGE ANALYSIS

5.1 It was realised for some time in T.R.O. that a more consistent form of presentation of damage information was required and as a result of many discussions between T.R.O. and Development Unit, Hull Structures, D.U. Report No. 204 was produced. This report is divided into two parts. A report similar to D.U. Report No. 204 was subsequently produced by T.R.O. for the Machinery. A similar format is in the process of being prepared for standard defect analysis of machinery data.

5.2 D.U. Report No. 204—Part 1

This report has been sent to all Plan approval centres, main outport offices and selected H.Q. departments and describes the procedure to be adopted in order to retrieve data from the T.R.O. database for use in hull damage investigations.

5.3 A damage investigation can be instigated for one of the following three reasons:

(i) Hull Structures Dept./Outport Investigation.
(ii) "Builder" Orientated Investigation.
(iii) "Owner" Orientated Investigation.

This information can be retrieved in a number of ways. Having specified the group of ships under review, a "General Study" is usually undertaken to provide the overall damage statistics. This is followed by successively more detailed studies, resulting in the identification of specific damage reports. Undernoted are some examples of the different types of request received in T.R.O.

5.4 Hull Structures/Outport Investigation

(a) Is a major damage an extreme case of a minor but frequent problem? Can it be related to other damages?
(b) Threshold limit exceeded? i.e. has the frequency of any damage increased? Is it related to a Rule revision?
(c) Initial design assessment: identification of which areas should be specially considered when developing an assessment procedure for approval purposes, i.e. new rule development or document procedure.
(d) What is the damage history of a particular rule requirement.

5.5 **"Builder" Orientated Investigation**

(a) Are there any anomolies between the damages to ships constructed by a particular builder and those constructed by other builders?

5.6 **"Owner" Orientated Investigation**

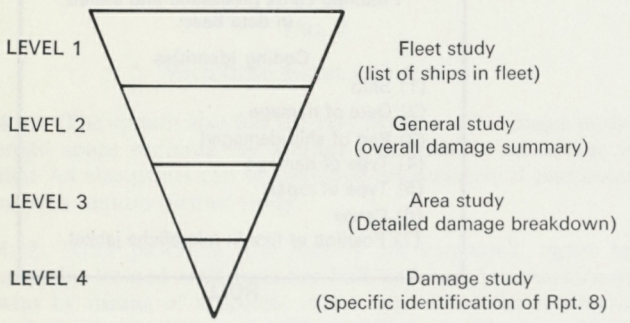
(a) How does the Owner's L.R. classed fleet of ships compare with similar L.R. classed ships?

(b) Which areas suffer the most damages and what are the causes?

5.7 Although the data can be divulged in analysed form, it should be noted that the information which identifies specific ships and determines the damage incidence rates for such ships, is confidential to the Society and on no account should be divulged to external organisations unless they are the Owners fleet under consideration.

5.8 The procedure consists of four steps as shown below. Each step provides more detailed information than the previous. The breakdown is as follows:

(i) Fleet study.
(ii) General study.
(iii) Area study.
(iv) Damage record identification.



5.9 **Schematic procedure**

Each of these steps is independent of the remainder. Therefore, if necessary, depending on the information required and considering the information already available, any of the steps can be considered separately.

5.10 **Fleet Study**

When considering damage statistics, it is very important to be aware of which ships are included in the analyses/investigation and the general particulars of such ships.

The Fleet Study provides this information, which is presented in the form of a list, comprising L.R. number, ship's name and up to eight additional ship particulars e.g., see Table 1.

In addition to this listing of the ship basic data, tables for various combinations of the ship particulars can be produced.

The first two columns of a particular listing are standard and the remaining eight are used to output any of the data coded in the General hull and machinery basic data files of the database. The pre-sorted order of the listing can be either by ascending L.R. number (which will be the case if no preference is indicated) or by any of the parameters of feature codes in either ascending or descending numerical order, e.g. arranged in order of ship length, speed, displacement, age, SHP, RPM, etc.

From the results of the Fleet study, certain ships may be identified which the user may wish to omit from the following

TABLE 1

	HULL	
(i)	L.R. number	Standard
(ii)	Ship name (original)	
(iii)	Date of build	OPTIONAL Full listing given in DU. Report No. 204 (Part 2)
(iv)	Moulded length	
(v)	Extreme draft amidships	
(vi)	Moulded depth	
vii)	Country of build	
(viii)	Ship builder	
(ix)	Design speed	
(x)	Class notation	
	MACHINERY	
(i)	L.R. number	Standard
(ii)	Ship name (original)	
(iii)	Date of build	OPTIONAL Full listing given in TRO Machinery damage Analyses (Part 2)
(iv)	Country of build	
(v)	Ship builder	
(vi)	Ship type	
(vii)	Number of screws	
(viii)	SHP	
(ix)	RPM	
(x)	Oil gland type	

General and Area damage studies. This can be achieved by specifying the relevant parameters of L.R. numbers which define these ships when requesting the General study.

5.11 **General Study**

The general analysis can be used to identify which areas of the ship are experiencing the greatest amount of damage. In addition to the incidences of damaged items by area, the cause of damage is presented. From this information, the user can determine whether a more detailed area damage study is required.

The information provided by the General study is as follows:

(i) Listing of the number of ships with the sum of damaged items.
(ii) Table giving the sum of damaged items and incidence rates to fifteen pre-defined areas of the ship's hull.
(iii) Table giving the sum of damaged items to the areas sub-divided by cause.
(iv) (ii) and (iii) for the sub areas that comprise the miscellaneous area.
(v) Listing of the builders of the ships included in the Study.
(vi) Listing of the ships ordered by the probability of occurrence of their incidence rates in comparison with the mean for the surveyed fleet.

The ship is divided into 15 areas, as indicated in Fig. 9 to align with the requirements of the current edition of the Rules and Regulations for the Classification of Ships. Only one area, miscellaneous, contains spaces in the ship which are not homogeneous. With the exception of the category "independent tanks" which are specific to gas ships, this area contains spaces which are either of secondary importance to hull strength or known to have a low incidence rate. The machinery is divided in a similar manner, but up to 13 areas. (Fig. 10).

The general study is very useful for comparing the rates of damage between two or more groups of ships.

The general study output (Fig. 11) lists each ship included in the analysis in the order of the probability of occurrence of its incidence rate compared with the average for all ships

DAMAGES REPORTED IN SPECIFIED AREAS

	AREA OF DAMAGE	SUM OF DAMAGED ITEMS BY AREA	PERCENTAGE OF TOTAL DAMAGES	INCIDENCE PER 100 MONTHS SERVICE	NO. OF SHIPS
01	FORE END STRUCTURE	85	11.8	1.26	39
02	FORECASTLE AND DECK	22	3.1	0.33	12
03	TRANSVERSE BULKHEADS (IN WAY OF CARGO SPACES)	50	6.9	0.74	32
04	LONGITUDINAL BULKHEADS (IN WAY OF CARGO SPACES)	4	0.6	0.06	2
05	BOTTOM STRUCTURE (IN WAY OF CARGO SPACES)	98	13.6	1.46	44
06	SIDE STRUCTURE (IN WAY OF CARGO SPACES)	198	27.5	2.94	62
07	DECK STRUCTURE (UPPER)	47	6.5	0.70	28
08	DECK STRUCTURE (TWEEN)	19	2.6	0.28	13
09	WEATHER DECK HATCHWAYS AND COVERS	21	2.9	0.31	10
10	TWEEN DECK HATCHWAYS AND COVERS	3	0.4	0.04	3
11	BRIDGE/DECK HOUSES AND DECKS (EXC.POOP & FCSLE)	3	0.4	0.04	2
12	ENGINE ROOM (INC.BOTTOM STRUCTURE)	34	4.7	0.50	19
13	AFT END STRUCTURE (EXC. ER.STERNFRAME & RUDDER)	33	4.6	0.49	20
14	RUDDER (EXC. BOW)	71	9.8	1.05	40
15	MISCELLANEOUS	33	4.6	0.49	21
TOTAL		721	100.0	10.71	85

FIG. 9

Damages reported in specified areas (Hull)

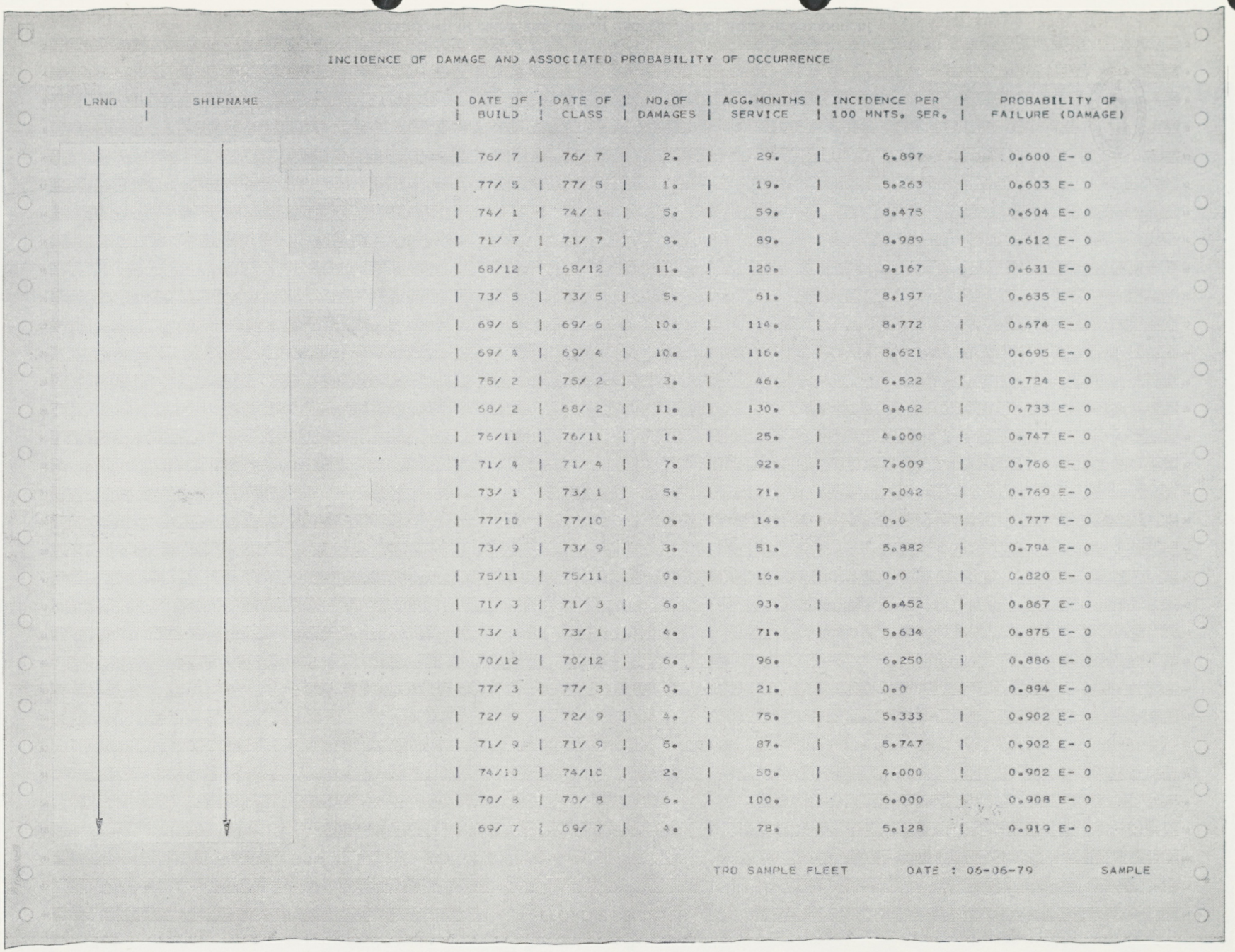
QUERY HOLDFL3,HOLDFL2A,HOLDFL2B,HOLDFL2,ILSDCON,TROCO PAGE 4

DAMAGES REPORTED IN SPECIFIED AREAS

	AREA OF DAMAGE	SUM OF DAMAGED LOCATIONS BY AREA	AGGREGATE MONTHS SERVICE	PERCENTAGE OF TOTAL DAMAGES	INCIDENCE PER 100 MONTHS SERVICE	NO. OF SHIPS
01	TRANSMISSION	108	6735	22.4	1.60	50
02	MAIN OIL ENGINE	178	6735	36.9	2.64	51
07	AUXILIARY OIL ENGINE	136	6735	28.2	2.02	30
09	GENERATORS	27	6735	5.6	.40	14
10	AUXILIARY BOILERS	11	6735	2.3	.16	10
11	STEERING GEAR	13	6735	2.7	.19	11
12	WINDLASS	10	6735	2.1	.15	9
TOTAL		483	6735	100.0	7.17	77

FIG. 10

Damages reported in certain specified areas (Machinery)



INCIDENCE OF DAMAGE AND ASSOCIATED PROBABILITY OF OCCURRENCE

LRNO	SHIPNAME	DATE OF BUILD	DATE OF CLASS	NO. OF DAMAGES	AGG. MONTHS SERVICE	INCIDENCE PER 100 MNTS. SER.	PROBABILITY OF FAILURE (DAMAGE)
		76/ 7	76/ 7	2.	29.	6.897	0.600 E- 0
		77/ 5	77/ 5	1.	19.	5.263	0.603 E- 0
		74/ 1	74/ 1	5.	59.	8.475	0.604 E- 0
		71/ 7	71/ 7	8.	89.	8.989	0.612 E- 0
		68/12	68/12	11.	120.	9.167	0.631 E- 0
		73/ 5	73/ 5	5.	61.	8.197	0.635 E- 0
		69/ 6	69/ 6	10.	114.	8.772	0.674 E- 0
		69/ 4	69/ 4	10.	116.	8.621	0.695 E- 0
		75/ 2	75/ 2	3.	46.	6.522	0.724 E- 0
		68/ 2	68/ 2	11.	130.	8.462	0.733 E- 0
		76/11	76/11	1.	25.	4.000	0.747 E- 0
		71/ 4	71/ 4	7.	92.	7.609	0.766 E- 0
		73/ 1	73/ 1	5.	71.	7.042	0.769 E- 0
		77/10	77/10	0.	14.	0.0	0.777 E- 0
		73/ 9	73/ 9	3.	51.	5.882	0.794 E- 0
		75/11	75/11	0.	16.	0.0	0.820 E- 0
		71/ 3	71/ 3	6.	93.	6.452	0.867 E- 0
		73/ 1	73/ 1	4.	71.	5.634	0.875 E- 0
		70/12	70/12	6.	96.	6.250	0.886 E- 0
		77/ 3	77/ 3	0.	21.	0.0	0.894 E- 0
		72/ 9	72/ 9	4.	75.	5.333	0.902 E- 0
		71/ 9	71/ 9	5.	87.	5.747	0.902 E- 0
		74/10	74/10	2.	50.	4.000	0.902 E- 0
		70/ 8	70/ 8	6.	100.	6.000	0.908 E- 0
		69/ 7	69/ 7	4.	78.	5.128	0.919 E- 0

TRD SAMPLE FLEET DATE : 06-06-79 SAMPLE

FIG. 11

Incidence of damage and associated probability of occurrence

TRO SAMPLE FLEET DAMAGE FOR PERIOD 01-01-68 . 31-12-78 PAGE NO. 001

(THE TOTAL OF DAMAGES IN THIS TABLE MAY EXCEED THE TOTALS IN TABLES 1&2.FOR FULL EXPLANATION-SEE PROCEDURAL DOCUMENT:SECTION 6.)

TABLE 4.

BREAKDOWN OF CAUSE AND TYPE OF DAMAGE FOR ALL ITEMS IN COMPONENT

COMPONENT DAMAGED	ITEM DAMAGED	TYPE OF DAMAGE	CAUSE OF DAMAGE	NO.OF DAMAGES	PERCENTAGE OF TOTAL DAMAGES	INCIDENCE PER 100 MONTHS SERVICE	NO.OF SHIPS
TRANSVERS BLKHD	GDR CON	BENT,BUKLD,IND	WEAR AND TEAR	1	2.0	.01	1
TRANSVERS BLKHD	PLATES	BENT,BUKLD,IND	CONTACT, RANGNG	2	3.9	.03	2
TRANSVERS BLKHD	PLATES	BENT,BUKLD,IND	EXCESS PRESSURE	2	3.9	.03	1
TRANSVERS BLKHD	PLATES	BENT,BUKLD,IND	SHIFT CARG.&H/W	1	2.0	.01	1
TRANSVERS BLKHD	PLATES	BENT,BUKLD,IND	UNK, NOT STATED	7	13.7	.10	6
TRANSVERS BLKHD	PLATES	BENT,BUKLD,IND	WEAR AND TEAR	2	3.9	.03	2
TRANSVERS BLKHD	PLATES	CRKD,FRACT	CARGO HANDLING	1	2.0	.01	1
TRANSVERS BLKHD	PLATES	CRKD,FRACT	FIRE	1	2.0	.01	1
TRANSVERS BLKHD	PLATES	CRKD,FRACT	GROUNDG,SUB-OBJ	1	2.0	.01	1
TRANSVERS BLKHD	PLATES	CRKD,FRACT	HEAVY WEATHER	3	5.9	.04	3
TRANSVERS BLKHD	PLATES	CRKD,FRACT	SHIFT CARG.&H/W	1	2.0	.01	1
TRANSVERS BLKHD	PLATES	CRKD,FRACT	UNK, NOT STATED	15	29.4	.22	11
TRANSVERS BLKHD	PLATES	CRKD,FRACT	WEAR AND TEAR	8	15.7	.12	7
TRANSVERS BLKHD	PLATES	LEAKING, POROUS	UNK, NOT STATED	3	5.9	.04	2
TRANSVERS BLKHD	PLATES	TORN,HLD,CLPSD	UNK, NOT STATED	1	2.0	.01	1
TRANSVERS BLKHD	STIFFS INC BKTS	CRKD,FRACT	UNK, NOT STATED	1	2.0	.01	1
TRANSVERS BLKHD	STIFFS INC BKTS	CRKD,FRACT	WEAR AND TEAR	1	2.0	.01	1
TOTAL NUMBER OF DAMAGES REPORTED				51	100.0	.76	32

RUN DATE 11.06.79

END OF DAMAGES REPORT

FIG. 12

Breakdown of cause and type of damage for all items in component

of the fleet under consideration. The ships are identified in order of maximum to minimum amount of damage experienced for a given time period.

When considering the incidence rates for the different areas, it should be remembered that the areas are of different proportions and the effects of damage on hull strength and safety can be much more significant for certain areas. Thus the area with the highest incidence rate is not necessarily the one to be given further attention.

The incidence rate per 100 months service is found in the following manner:

$$I = \frac{\text{Number of Damaged items}}{\text{Aggregate Months Service}} \times 100$$

The probability used to order the damage statistics for the individual ships is the probability of the particular ship having an incidence rate greater than that expected when compared with the average for all ships being considered. This probability is calculated using a Poisson distribution model which takes account of the Fleet incidence rate, the ship incidence rate and the months service.

5.12 Area study

This analysis gives a detailed breakdown of the damage in a particular area. Each area consists of components, e.g. bulkheads, side shell, etc. which in turn are made up of items, e.g. plates, stiffeners, frames, etc. It breaks down damages in sufficient detail to identify the items giving most trouble.

An Area study provides the following information:

(i) Count by Item presented by Component.
(ii) Count by Item presented by Component and Item.
(iii) Count by Type of Damage presented by Type of Damage.
(iv) Count by Type of Damage presented by Component, Item, Type of Damage and Cause. (Fig. 12).

5.13 Damage record identification

Once the cause, types of damage and items/components/areas damaged which are of interest are identified, then this information is used to obtain the list of ships to which the damages refer. In addition to the ship name and L.R. number, the date of the defect and position of the film in the microfiche jacket are given and thus the specific report 8 which details the damage is identifiable. This report can then be viewed in T.R.O., and if required, a photocopy of the report obtained.

5.14 Keep files

To minimise the time and expense involved in accessing the information stored in the database, temporary Keep files are created from the main database records for the ships under consideration. A keep file will be maintained for one month after its creation. Prior to its deletion, the user is notified and if the investigation is being actively progressed the file will be maintained for a further period of time.

5.15 D.U. Report No. 204—part 2

This report lists the following:

1. Ship type definition and codes.
2. Summary of recorded classification information.
3. Summary of basic ship information held in T.R.O.
4. Ship area identification and codes.
5. Detailed space identification and codes.
6. Detailed item identification and codes.

6. AD-HOC ENQUIRIES

6.1 An ad-hoc enquiry is indeterminate and nearly always an individual "one-off", designed to meet the slant of the particular question. Updating of previous enquiries also falls into this category, as do those internally generated to further check the consistency of the original coding. They range in complexity from lists of ships having certain basic data and/or defect parameters, through tabular output, and on to defect incidence rates or reliability figures.

6.2 Because the structure of the database is sound and the enquiry language used, so flexible, the limits to answering any enquiry are only dependant on:

(i) The relevant information being coded.
(ii) The ingenuity and comprehension of the person processing the enquiry.

6.3 This type of enquiry may come from any source, e.g.:

1. ICD
2. Chief Surveyors.
3. IACS.
4. Research and Development Bodies.
5. Government Agencies.
6. TID
7. Machinery Reports Department.

Requests for information are also received from other Head Office technical and non-technical departments and Outport Offices.

6.4 Some typical examples are as follows:

1. Main and auxiliary engines fitted in U.K. built ships between 1971 and 1975 having a BHP between 500 and 5000.
2. Roller sternbush bearing defects.
3. Bow and stern door damage on Ro-Ro ships.
4. Chain cable and anchor losses and defects to windlasses.
5. Rudder coupling defects.

7. CONTINUOUS MONITORING OF DEFECTS

7.1 This section of the paper deals with the procedure used to monitor trends of damage falling outside a given incidence range and is complementary to the philosophy and application of D.U. Report No. 204. A similar process related to monitoring transmission damage is prepared.

7.2 The classed fleet is divided into the following four main groups:

GROUP
- A Cargo carrying ships $\geqslant$ 90 metres in length.
- B Cargo carrying ships $<$ 90 metres in length.
- C Ships generally $<$ 90 metres in length and not cargo carrying.
- D Non-propelled ships.

These groups are further divided into sub-groups:

GROUP
A is divided into 12 sub-groups.
B is divided into 7 sub-groups.
C is divided into 7 sub groups
D is divided into 2 sub-groups.

7.3 Each ship is monitored for damage occurring to items in specific areas of a ship, e.g. Fore end structure, Forecastle and Deck, Trans. Bhds., etc.

7.4 One of the major advantages of this procedure is that damage information is monitored in a consistent form for all types of ships. Thus, comparisons of incidence rates can be made for a particular area of a ship, between different types of ships.

7.5 Damage data is coded daily and stored on the database within $1\frac{1}{2}$ to $2\frac{1}{2}$ weeks of receipt in Head Office. Holidays, sickness and the time elapsed between incident and coding are allowed for in the system which is based on data added in calendar time to the database.

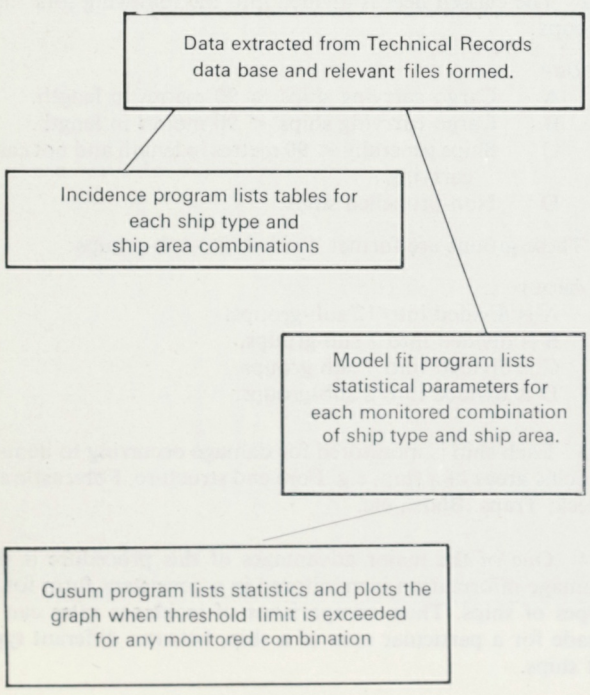
7.6 As damage is reported at random, even ordering the data into say, area of ship, type of ship, age and size still leaves two main statistical difficulties. One is the varying number of ships at risk each month and the other is that the damage rate fluctuates between ships and ship types. Because of the small number of ships at risk in any one group and the relatively low frequency of damage, it is considered prudent to use all of the data available for a given ship type.

7.7 The Cusum Chart is an informative method of graphical presentation for series data, especially where the mean level of the damages is subject to small but important changes in level. These charts are therefore useful for monitoring purposes when any departure from a target damage rate needs to be identified. They are also applicable to the retrospective examination of accumulated data or for comparison with other series data.

7.8 Compared with conventional methods of plotting series data, cusum charts have two main advantages. Firstly, an indication of a change in the mean level is given by the general slope over a sequence of points and secondly, they are more efficient because equally reliable decisions can be made with less sample information.

7.9 The principal feature of cusum techniques is that successive values (monthly) of a variable (damages) are compared with a pre-determined target value (incidence rate), and the cumulative sum of deviations from this value is plotted on a chart or recorded in a tabulation. If the cumulation reaches or exceeds a pre-determined threshold value, then this is taken to indicate that a change has occurred in the incidence rate.

7.10 Where the purpose of a cusum procedure is to detect off-target conditions, rather than to present a graphical summary of the series data, the information available at any point in time (monthly) can be represented numerically. The operations involved can be readily summarised in a logical form suitable for direct incorporation into a computer routine.



7.11 **Outline of system**

A suite of programs has been written to extract and analyse the relevant data from the Technical Records database. This is shown in adjacent column below, and with examples of the output.

7.12 **Definitions and analysis procedure**

The monitored value is the count of damaged items recorded each month weighted by the number of ships at risk during the same month. This is a variation of the incidence rate previously defined on page 15.

7.13 The target value, initially, has been set as the average monthly count recorded over the three years from March 1974 until February 1977. The monthly monitoring started with damages recorded in March 1977 and processed rapidly until the system was up-to-date. The target value can, however, be set at any desired level.

7.14 The threshold values are set empirically at a reasonable distance above and below the target value for all the monitored combinations, i.e. when the trend of the damage count exceeds, or is less than, that recorded over an earlier pre-determined period, a computer signal will graphically indicate this change. The percentage required before threshold exceedence is signalled can be varied.

7.15 Exceedence of the upper threshold value can be due to one of four possibilities:

(i) One or two ships have sustained a significant amount of damage as the result of a single incident.
(ii) A group of ships have sustained more damage than usual over a given period of time.
(iii) There is a trend of increasing damage occurring over a limited period of time.
(iv) There is an upward drift caused by an insignificant increase in the damage rate over a longer period of time.

7.16 In general, each of these four conditions can be identified by the shape of the cusum graph.

(i) The ship or ships involved are identified by reference to the database. Any technical relevance is assessed by reference to the class report.
(ii) The ships involved are similarly identified by reference to the database. Further research is carried out to establish a common linkage, e.g. all are of a certain standard type. Then an Area study is carried out to identify the type of damage involved.
(iii) This is sorted out by reference to the incidence listings and also by making Area studies over selected time intervals. Preliminary technical assessment of the damages is then made to ensure that they are valid.
(iv) It is established statistically that there is a drift of the chart. This does not involve any technical assessment.

7.17 A computer signal indicating that the lower threshold value has been passed can be interpreted in two ways:

(i) An increase of damage having been sustained during the model fit period.
(ii) A downward drift.

7.18 A record is maintained of all computer signals indicating threshold exceedence. The record states the statistical significance established and whether or not the target value is to be reset.

7.19 A regular report summarising any findings will be circulated on a limited basis. There is also a systematic analysis of each ship type and ship area combination utilising the incidence listings. The findings will also be circulated in a bulletin format.

MAIN SHIP TYPE GROUP - SHIPS GENERALLY LESS THAN 90 METRES AND NOT CARGO CARRYING

SHIP TYPE GROUP - RESEARCH

PERIOD CONSIDERED - 1- 3-74 TO 28- 2-77

NO. OF SHIPS AT RISK = 59 AGGREGATE MONTHS SERVICE = 1820

AREA OF DAMAGE	NO. OF DAMAGES	INCIDENCE	95% CONFIDENCE INTERVAL LOWER	UPPER	PROB. RELATED TO THE AVERAGE INCIDENCE FOR SIMILAR SHIPS
FORE END STRUCTURE	2.	0.10989	0.06313	0.36773	0.999 E - 0
FORECASTLE AND DECK	8.	0.43956	0.24050	0.84970	0.629 E - 0
TRANSVERSE BULKHEADS (IN WAY OF CARGO SPACES)	0.	0.0	0.0	0.0	0.665 E - 0
LONGITUDINAL BULKHEADS (IN WAY OF CARGO SPACES)	0.	0.0	0.0	0.0	0.201 E - 0
BOTTOM STRUCTURE (IN WAY OF CARGO SPACES)	1.	0.05495	0.05279	0.26818	0.999 E - 0
SIDE STRUCTURE (IN WAY OF CARGO SPACES)	7.	0.38462	0.20523	0.77508	0.897 E - 0
DECK STRUCTURE (UPPER)	7.	0.38462	0.20523	0.77508	0.854 E - 0
DECK STRUCTURE (T'WEEN)	0.	0.0	0.0	0.0	0.155 E - 0
WEATHER DECK HATCHWAYS AND COVERS	0.	0.0	0.0	0.0	0.155 E - 0
TWEEN DECK HATCHWAYS AND COVERS	0.	0.0	0.0	0.0	0.000 E -12
BRIDGE/DECK HOUSES AND DECKS (EXC. POOP & FCSLE)	0.	0.0	0.0	0.0	0.747 E - 0
ENGINE ROOM (INC. BOTTOM STRUCTURE)	0.	0.0	0.0	0.0	0.999 E - 0
AFT END STRUCTURE (EXC. ER.STERNFRAME & RUDDER)	8.	0.43956	0.24050	0.84970	0.898 E - 0
RUDDER (EXC. BOW)	9.	0.49451	0.27697	0.92312	0.688 E - 0
STERNFRAME	2.	0.10989	0.06313	0.36773	0.209 E - 0
EQUIPMENT (BOW)	10.	0.54945	0.31444	0.99554	0.103 E - 0
MISCELLANEOUS	1.	0.05495	0.05279	0.26818	0.975 E - 0
TOTAL	55.	3.02198	2.32885	3.92618	1.000 E - 0

FIG. 13

Example of incidence listing by ship type

CUSUM MODELS.
****

N.B. MODEL BASED ON MAIN SHIP TYPE GROUP DATA PROGRAM RUN DATE : 30/ 3/79

IDENTITY CODE : C005
SHIP GROUP : SHIPS GENERALLY LESS THAN 90 METRES AND NOT CARGO CARRYING
SHIP TYPE : RESEARCH
SHIP AREA : ALL
PERIOD CONSIDERED : 3/74 TO 2/77

MODEL PARAMETERS.
****

MODEL FITTED IS NEGATIVE BINOMIAL.

NO. OF ELEMENTS (I.E. MONTHS)	=	36	
AVERAGE NO. OF SHIPS PER MONTH	=	50.556	
DEFECT RATE PER MONTH (M)	=	1.5278	
95% CONFIDENCE INTERVAL FOR M	=	1.1774 TO	1.9849
SKEWNESS (M)	=	0.3850	
DISCRETENESS (M)	=	0.0461	
NEGATIVE BINOMIAL PARAMETER K	=	27.3810	
NEGATIVE BINOMIAL VARIANCE	=	1.6130	
SHIP DEFECT RATE PER 100 MONTHS (MI)	=	5.5908	
95% CONFIDENCE INTERVAL FOR MI	=	5.2016 TO	5.9884
SKEWNESS (MI)	=	0.0642	

FIG. 14

Example of model fit output

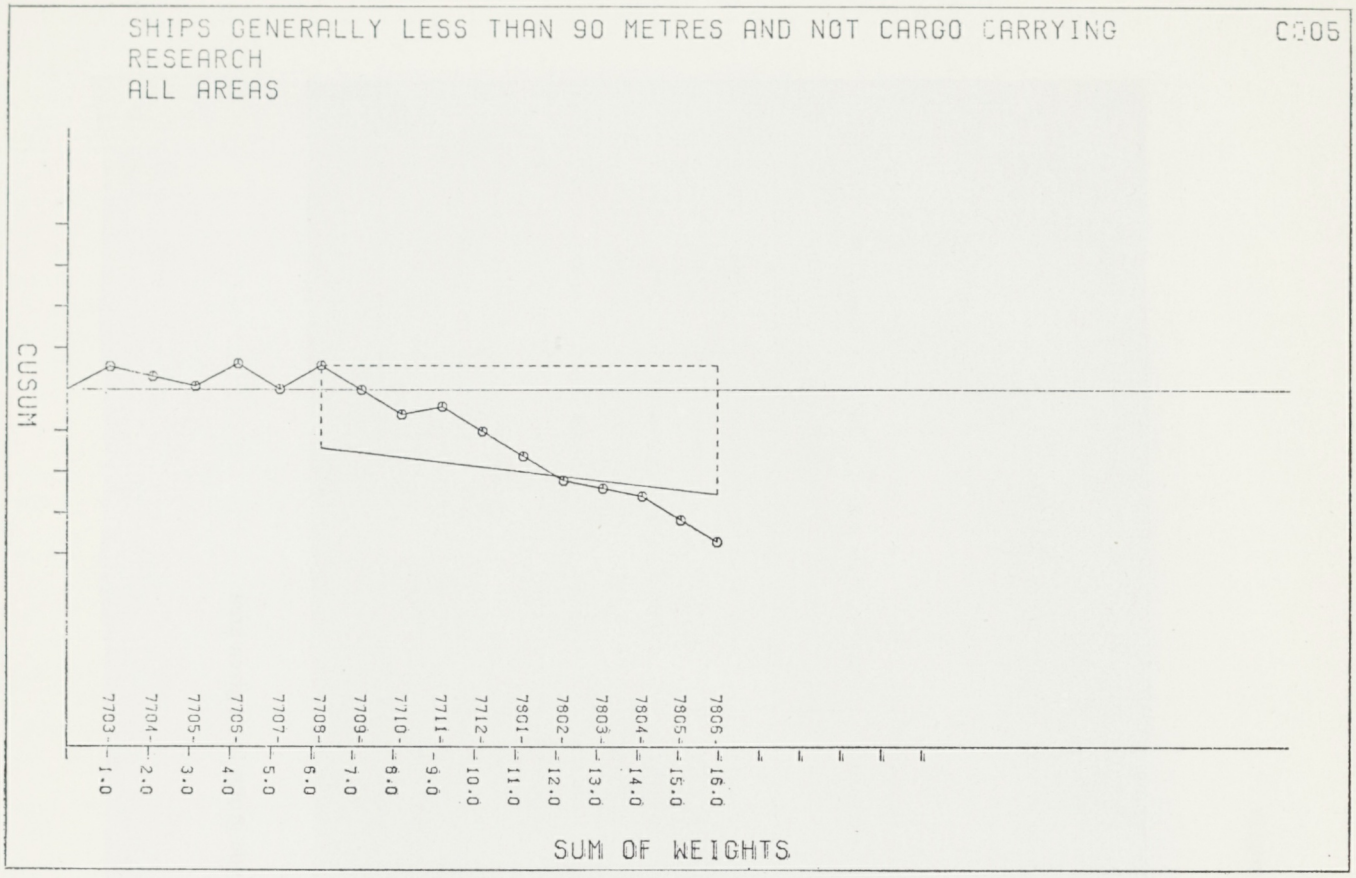


FIG. 15

Example of Cusum trend output

7.20 Because the calendar months service varies in size between ship type groups, and each group is in effect a sample, the incidence rates so calculated cannot be expected to be the true incidence for a particular group. Moreover, we rather expect an incidence somewhere within a small range. The confidence limits cover the range within which the "true" incidence can be expected to lie and is dependent on the number of months service. The greater this number the smaller the width of the range. For example, see Table 2.

TABLE 2

	Number of damages	Service months	Incidence rate	Confidence limits of the incidence
A	4	25	0.16	0.08 to 0.39
B	16	100	0.16	0.10 to 0.26
C	160	1000	0.16	0.14 to 0.19

In comparing the difference statistically, between comparable incidence rates, it is important to determine whether the difference is due to sampling fluctuations caused by the total months service or if the difference is due to other factors. The significance can be measured by comparing the confidence limits of the incidences involved. If the ranges overlap then the difference between the incidences is not statistically significant and can be considered due to sampling fluctuations.

7.21 The final column in the tables under Figs. 13 and 16 is the probability of the incidence rate being greater than the expected value when compared with the average for the same area in comparable groups of ships. This probability is calculated using a Poisson distribution model which takes account of the overall incidence, the individual group incidence and the months service.

As a general rule, the calculated values with an exponent value greater than one have an incidence rate worse than average.

8. RELIABILITY

8.1 Reliability is the probability of not failing for the first time and its value ranges from 100% (or one) to zero. Reliability needs to be related to a time period because, as complete reliability is expected at the beginning, and nothing lasts forever, there is a progressive failure as time elapses. This progressive failure can be (a) random, and is shown by a constant failure rate over a period of time or (b) due to a design weakness indicated by an irregular failure rate, possibly with a maximum at a certain point in time. Moreover the data is made more difficult to analyse by damages only being reported for the first time during a periodical survey.

8.2 Reliability can realistically only be applied to a group in the form, e.g. 90% reliable after the first five years, which means that 90 ships out of 100 will have no failure during their first five years service. This is not directly related to an individual ship, except that the odds are nine to one on not having a failure.

8.3 Reliability figures are useful in comparing the performance of similar groups, e.g. SD14's and other standard series.

8.4 Correct terminology is of paramount importance in all aspects of the work dealt with in T.R.O., because reliability

MAIN SHIP TYPE GROUP - SHIPS GENERALLY LESS THAN 90 METRES AND NOT CARGO CARRYING

AREA OF DAMAGE - FORECASTLE AND DECK

PERIOD CONSIDERED - 1- 3-74 TO 28- 2-77

SHIP TYPE GROUP	NO. AT RISK	AGG. MONTHS SERVICE	NO. OF DAMAGES	INCIDENCE	95% CONFIDENCE INTERVAL LOWER	UPPER	PROB. RELATED TO THE AVERAGE INCIDENCE FOR SIMILAR SHIPS
TUGS	791	22960	46.	0.20035	0.15082	0.26661	1.000 E - 0
BARGES & PONTOONS	322	7510	18.	0.23968	0.15453	0.37598	1.000 E - 0
FISHING	763	22720	90.	0.41373	0.33855	0.50583	0.993 E - 0
RESEARCH	59	1820	8.	0.43956	0.24050	0.84970	0.629 E - 0
OTHERS	41	1255	9.	0.71713	0.40166	1.33371	0.137 E - 0
DREDGERS	145	4515	44.	0.97653	0.72912	1.30503	0.878 E - 4
SUPPLY (OKSV)	156	4160	126.	3.02885	2.54615	3.60389	0.590 E - 8
TOTAL	2277	64940	345.	0.53126	0.47816	0.59028	

FIG 16

FIG. 16

Example of incidence listing by ship type group for a given area

PROBABILITY OF NOT FAILING (INITIAL FAILURE) PAGE 1

TRD SAMPLE FLEET -TRANSVERSE BULKHEADS (IN WAY OF CARGO SPACES)

COL1	COL2	COL3	COL4 (COL40)	COL5 (COL50)	COL6	COL7	COL8	COL9	COL10
1	000098	000004	00000 0000.0000	000005 0003.0001	95.0001	0.0421	.9579	0.9579	0.0215
2	000092	000005	00003 0001.0833	000005 0002.8334	87.9167	0.0569	.9431	0.9034	0.0313
3	000084	000004	00001 0000.0833	000007 0002.8333	78.9166	0.0507	.9493	0.8576	0.0376
4	000076	000003	00002 0001.9167	000006 0004.5000	74.4167	0.0403	.9597	0.8230	0.0413
5	000068	000007	00001 0000.2500	000010 0004.7500	62.0000	0.1129	.8871	0.7301	0.0496
6	000057	000006	00001 0000.0833	000009 0005.0834	52.1667	0.1150	.8850	0.6461	0.0545
7	000047	000001	00001 0000.5000	000006 0002.2500	42.7500	0.0234	.9766	0.6310	0.0554
8	000040	000000	00000 0000.0000	000013 0009.0834	36.0834	0.0000	1.0000	0.6310	0.0554
9	000027	000001	00003 0001.1666	000009 0003.9999	20.1665	0.0496	.9504	0.5997	0.0609
10	000015	000001	00000 0000.0000	000012 0007.0833	10.0833	0.0992	.9008	0.5402	0.0787
11	000003	000000	00000 0000.0000	000003 0001.7500	1.7500	0.0000	1.0000	0.5402	0.0787

PROBABILITY OF NOT FAILING (INITIAL FAILURE)

COL1: SERVICE YR INTERVAL (E.G. 0-1 GIVEN AS 1)

COL2: NO.AT RISK AT BEGINNING OF INTERVAL

COL3: NO.FAILED DURING INTERVAL

COL4: NO.DISCLASSED DURING INTERVAL (COL40 IS ACTUAL SERVICE)

COL5: NO.AT RISK FOR PART OF INTERVAL (COL50 IS ACTUAL SERVICE)

COL6: EFFECTIVE NUMBER AT RISK

COL7: PROPORTION FAILING

COL8: PROPORTION SURVIVING

COL9: CUMULATIVE PROPORTION SURVIVING

COL10 STANDARD ERROR

FIG. 17

Probability of not failing

not only refers to whole units, e.g. ships, but also to parts of a ship, e.g. fore-end structure. It is therefore absolutely essential that the components being considered are precisely identified and compatible. This is also applicable to failure. Failure can be defined as a defect caused by inadequate design or manufacture, but not due to operator causes such as collisions or groundings. Further, a defect can be defined as buckling of a plate or fracturing of a girder within the ship's structure being assessed.

8.5 Reliability figures are usually derived from data acquired during years of service experience. However, Development Unit Report No. 220 describes how a mathematically equivalent probabalistic model can be used to determine permissible design criteria. This direct calculation method for the appraisal of scantlings implies that any constraints must be identified and stated explicitly. These include loading and strength as well as workmanship and quality control. Thus, the actual structure, as opposed to an ideal structure, can be simulated over a specified time span. The adequacy of this mathematical model can be verified by reliability figures obtained from the service data recorded by T.R.O.

8.6 The technique used in T.R.O. for the measurement of reliability is a refined version of the life tables used extensively by actuaries and is one of the oldest methods of statistical technique.

8.7 The output is subject to input cards which define the parameters and definitions. It is numerical and presented in a standard 12 column form as described below:

Column 1 The range is 0–1, 1–2, 2–3, etc. and refers to the service years. The extent of the range will vary according to the basic data parameters.

Column 2 The number at risk at the beginning of each interval depends upon:

(i) Not having failed in a previous interval.
(ii) Not disclassed in a previous interval.
(iii) In the period being considered, the ship having had sufficient service to be included in the interval.

Column 3 The number of failures depends upon what is defined as a failure.

Column 4 The number of ships disclassed and the number of failures during the interval.

Column 40 The service years of the number shown in column 4.

Column 5 The number of ships at risk for part of the interval, but still in class and having no failure.

Column 50 The service years of the number in Column 5.

Column 6 The effective number of ships at risk and is calculated as Column (2)–(4)+(40)–(5)+(50) $= l_x$.

Column 7 The proportion failing which is calculated as Column (3)÷(6) $= q_x$.

Column 8 The proportion surviving $= 1-(7) = p_x$.

Column 9 The cumulative proportion surviving $= P_k = p_1 \times p_2 \times p_3 \times \ldots p_k$ This is the reliability value.

Column 10 The standard error of column nine which for the kth service year is calculated as,

$$S_k = P_k \left[\sum_{x=1}^{x=k} \frac{q_x}{l_x p_x} \right]^{\frac{1}{2}}$$

This allows the range of the reliability value to be established.

8.8 The example in Fig. 17 shows that the reliability after five years is 73 per cent. and that we are 95 per cent. certain that the range lies between 63 and 83 per cent. The reason for this wide range is that 34 ships (the summation of the first five in Column 5) out of 98, i.e. one third, were less than five years old. The effective sample size was therefore quite small.

8.9 This realistic measure for assessing reliability is preferred to the usual method invoking the mean time between failures (MTBF) and the negative exponential distribution. This is because the MTBF cannot be accurately determined from T.R.O. data which only allows for the counting of failures at given points in time. In any case, the MTBF assumes a constant failure rate where as the life table method makes no conditions about the failure rate.

9. REGULAR BULLETINS

9.1 These are confidential and only issued to Principal Surveyors and above. They consist of four sections which are not necessarily issued simultaneously.

The sections are a combination of statistical and technical comment with emphasis on the subject being analysed.

9.2 The four sections consist of the following:

(i) Results of monitoring with comments whenever relevant and cross referenced with (ii) below.
(ii) Systematic analysis of each ship type and ship area, utilising the incidence listings in addition to the General and Area studies.
(iii) Interesting and topical N.D.L. cases expanded into investigations, also internal and external enquiries which are considered worthy of wider Head Office circulation.
(iv) T.R.O. instigated 'in depth' articles such as those which appear in 100A1 and other technical publications.

10. LIMITATIONS

10.1 If T.R.O. admits to having a most comprehensive data store, perhaps the largest of its kind, it is important that it does not ignore the shortcomings of the system, the principle of which are as follows:

10.2 Data is received only on L.R. classed ships, i.e. around 30 per cent of the world fleet. This is not too important since the 'sample' is sufficient to ensure accurate conclusions being drawn from behaviour analyses generally.

10.3 Technical Records are almost entirely dependent upon Surveyor's reports. If these are incomplete, or deficient in technical content, the data is, of course, affected accordingly. Furthermore, repairs and replacements are often made by ship's personnel under normal maintenance without reference to the Surveyor's. This applies particularly to hatch covers.

10.4 Time lag between the defect being found and same being recorded into the system.

10.5 The problem of confidentiality. For example, the comparison of two sister or similar ships built at different yards. The Society is in a position of trust in relation to information obtained through Surveyors, and in order to discharge its duty with integrity and impartiality, it must maintain strict discretion in divulging such information.

10.6 Information which would be useful in assessing the severity of a damage is not available to the Society, such as operating conditions, delay times, cost of repairs and precise location of the damage.

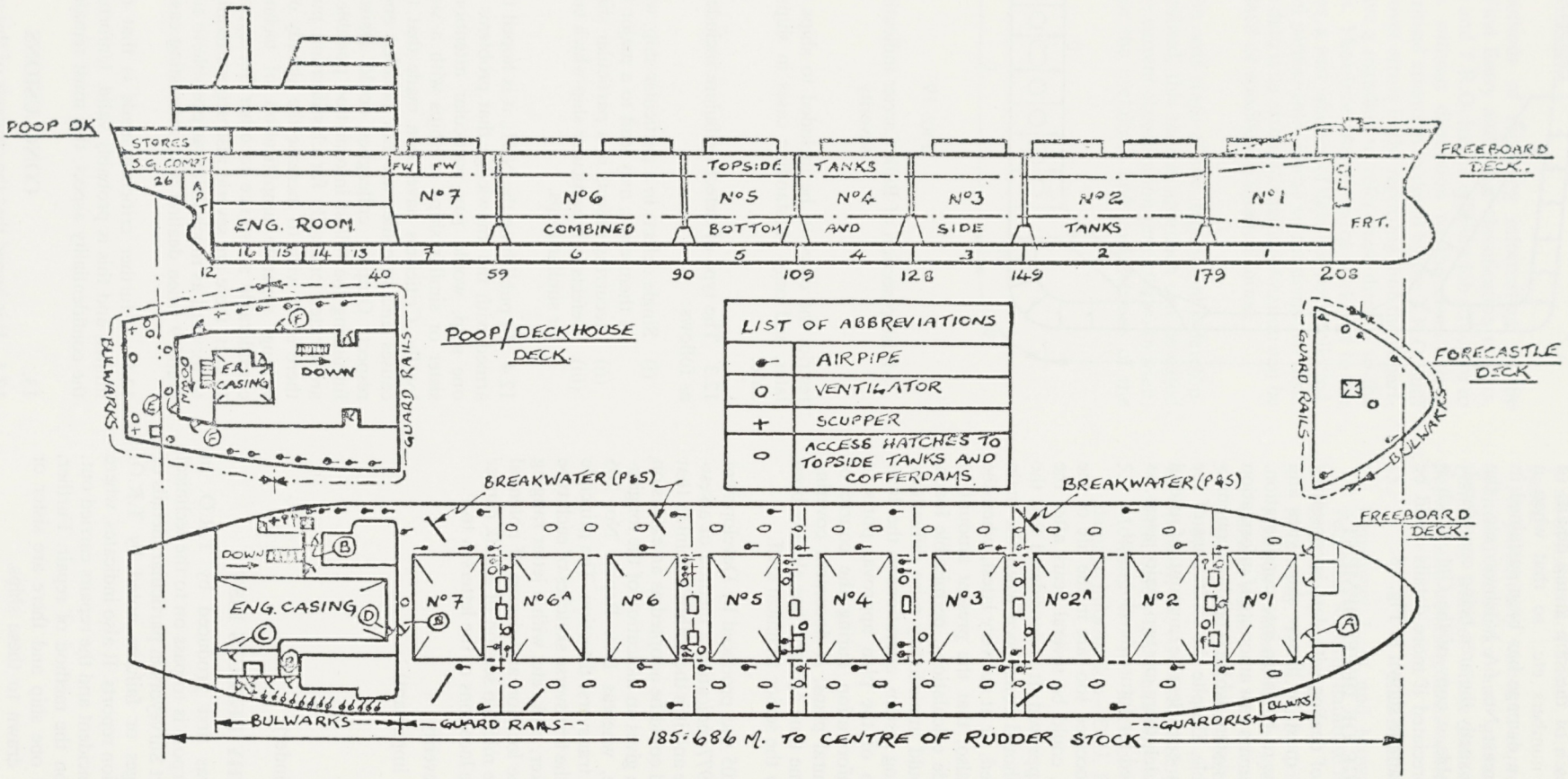


FIG. 18

Copy of Rpt C11 sketch

10.7 Information missing from Basic data cards which could be either 'not applicable' or 'not readily available'.

T.R.O. would like a sketch of the ship giving details of compartments and frame numbers etc., so that when a Surveyor reports, e.g. that a damage has been sustained in way of No. 2 hold or abreast No. 6A hatchway etc., the coding operator will know exactly the area being considered. As this sketch is not available, a copy of the C11 sketch is made and it would be appreciated if more details could be given as indicated in the example shown in Fig. 18.

11. THE NEXT STAGE OF DEVELOPMENT

11.1 The current method of dealing with data is constantly under review, as indeed it must be if new ship types and methods of construction are to be taken into consideration. However, T.R.O. does not amass vast amounts of information just to remain unused in the system, which is neither economically nor technically justifiable. Despite the limitations of the existing system, there is a considerable amount of useful information available of which there are two major areas, as undernoted, to be considered for future development.

11.2 The basic data is processed too late in the life of the ship, which in some cases, could be several years after the main structural plans are approved. It is considered that the coding of the basic data should commence when the main structural plans are approved, or at the very latest, when the steelwork is commenced, also, that the present amount of data be increased to include calculations, permissible loads, steel weights, etc. This would immediately raise difficulties, such as, amending the coding system, alterations to the data-base and the co-operation of the plan approval ports in compiling the required information during the course of approving the main structural plans. A document covering this area was produced some time ago and has already been discussed at some length by the senior technical staff.

11.3 A draft report No. 205 was produced by Development Unit—Hull Structures in 1977 indicating a method of assessing the severity of a damage and it is the author's opinion that the principle of this method could be adopted as an extension of the present system which gives an indication of the longitudinal extent of a damage, whereas DU. Report No. 205 includes the location in the transverse direction. The principle innovation of the report is the transverse sketches of each type of ship, e.g. container, tanker, bulk, etc. with a letter ranging from A to F to indicate the location and degree of potential severity. An example of the midship section of a bulk carrier is shown in Fig. 19 with the locations of the letters A to F.

Categories of severity

A (most important)
B
C
D
E
F (remainder)

12. NOTEWORTHY DEFECTS LIST

12.1 This publication was first produced by T.R.O. in September 1971 and its purpose is to pass on to the technical staff in general and Outport Surveyors in particular, details of interesting defects, damages or failures noted by T.R.O. when examining classification reports. It also indicates, where possible, the cause of the incident and the repairs carried out, together with comments on the method of repair. Further, where a defect occurs on one ship and there are sister or similar ships, attention is drawn to these ships.

12.2 In view of the specialization in ship types and methods of construction in recent years, it was considered advisable to restrict the cases to be included to ships built in 1965 and later, and only outstanding cases in ships built before this date.

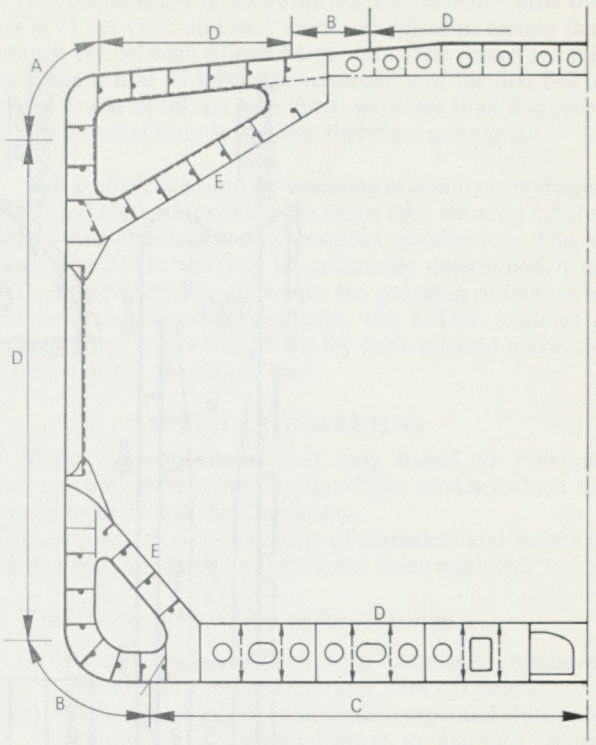


FIG. 19

Midship section of Bulk Carrier indicating categories of severity

12.3 The type of defect or failure included in the NDL are as follows:

(i) Single defects in a particular ship, which even if minor in themselves, may lead to a major failure.
(ii) Recurring defects in a particular ship.
(iii) Defects in a particular ship which could occur in sister or similar ships.

12.4 In publishing the NDL, it is hoped that the Surveyors, armed with the knowledge that problems were occurring in one ship, would pay particular attention when surveying sister or similar ships or ships with a similar construction locally. Criticisms have been made that the explanation of causes and remedies are not detailed enough, and in this respect, Outport colleagues could assist considerably by furnishing the fullest information possible. Reports 8 and 9 are written primarily for classification purposes and whilst there is no wish to increase the already onerous amount of writing, separate amplification of technical details is of considerable assistance to other Surveyors using the NDL. In fact, there are several instructions requiring the Surveyors to forward as much detail as possible to supplement Reports 8 and 9 when dealing with interesting cases.

12.5 A further criticism made is that distribution is too limited and this is probably valid. Unfortunately, because of the confidentiality aspect, this must remain so.

13. CONCLUSIONS

13.1 It is hoped that the contents of this paper will bring the existence of T.R.O. to a wider audience in addition to a greater awareness of its function and capabilities. It does not

detail all the work and checking for accuracy processes, nor the continuous questioning carried out in the department, but it does convey the theme.

13.2 Existing methods of reporting information to the Society, namely First Entry and other classification reports, have been utilised and T.R.O. has an efficient job structure to handle this work without disruption to the classification procedures. The critical attention to detail by the T.R.O. staff does however uncover errors in the reporting, but the department does not have a mandate to refer these directly to the Outport Surveyors. Therefore, with no extra workload to the Society's employees, a vast amount of data has been collected, checked, coded and permanently stored on the computer disk. The storage of the data is so arranged that information can be extracted in standard or specifically ordered forms.

13.3 Although the next stage of the department's development has been outlined, this radical approach can be eased into by refining the current classification procedures. In itself, this would increase the usefulness and completeness of the information.

14. ACKNOWLEDGEMENTS

The Author, wishes to express his thanks and appreciation to all of the staff of T.R.O. who assisted him in compiling this paper.

He particularly wishes to express his appreciation for the dedicated assistance and guidance given by Mr. L. N. Heminway without whose patience and understanding this paper would not have been written.

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Lloyd's Register Technical Association

Discussion

on

Mr. T. Sullivan's Paper

TECHNICAL RECORDS—1979

Paper No. 1. Session 1979-80

FOR PRIVATE CIRCULATION AMONGST THE STAFF ONLY

The author of this paper retains the right of subsequent publication, subject to the sanction of the Committee of Lloyd's Register of Shipping. Any opinions expressed and statements made in this paper and in the subsequent discussion are those of the individuals.

Hon. Sec. S. M. Wehrle
71 Fenchurch Street, London, EC3M 4BS

Discussion on Mr. T. Sullivan's Paper

TECHNICAL RECORDS—1979

CONTRIBUTIONS

From Mr. R. M. Leach:

T.R.O. investigation reports on various subjects are constantly being called for by Classification Reports Machinery Department. Such reports save hours of manual searching through 11,000 ship classification files and enable analyses to be carried out which a few years ago would not have been possible.

The presentation of the statistics produced in such reports are often difficult to interpret if one is not a statistician. For instance, we are told that the incidence of cracked and broken specified components per 100 years of service is 2·1. At first sight it is difficult to envisage a component in service for 100 years on a classed ship! Furthermore, it is difficult to decide from one's own practical experience whether this stated incidence is acceptable or not in the circumstances. If, however, the same statistics could be presented in a more readily understood form such as: if there are X number of ships in service fitted with component Y; of these ships, Z have been found to have defective 'Y' components during the first 5 years in service—the figures would be meaningful at a glance to the practical man and indicate immediately whether the incidence was excessive or not.

With regard to paragraphs 4.17 and 12.4 of the paper I would like to confirm that the use of such wording as "Minor Repairs Effected" is of no value on Classification Reports for machinery and has been discouraged. Whereas, it cannot be disputed that the quality of output from T.R.O. is dependent upon the right sort of information being received from the Surveyors in the Outports, certain fundamental principles must be maintained in the writing of classification reports. Facts, and only facts, should appear in these reports; opinions or loose statements are not acceptable and reports containing such references may be returned to the writer for amendment. Circular 2336 is quite clear in these matters. Classification reports are constantly being exhibited at Owners request in H.Q. at an increasing rate. Copies of these reports can be obtained by solicitors and other parties acting in litigation cases. Sales of ships are regularly dependent upon classification reports being found satisfactory to prospective purchasers. Statements which are not supported by facts can cause acute embarrassment to the Society not only immediately following a survey but also at any time during the ships subsequent life and sometimes for several years after the ship has been scrapped.

It is, however, acknowledged that there is a need for more specific and detailed information to be obtained as basic data, and also for service records, if the work of T.R.O. is to be extended.

From Mr. G. J. Talbot:

Mr. Sullivan, I suspect, has written this paper with some trepidation and more than a little courage. It is a ship biased paper, but even more so, it is statistically biased. In my generation, statistical training was considered unnecessary.

Mr. Sullivan's practical hull expertise has in this paper been allied to Mr. Heminway's statistical expertise and the result is this very interesting paper.

It is not easy for anyone reading this paper to raise queries on the spur of the moment—but do not hesitate to do so because at least 90% of your colleagues are in the same position. Although this paper is ship biased, nevertheless, it is equally applicable to the Engineers.

What I should like to do is place before you some facts and figures which I hope will enable you to appreciate the background to the paper. The world is becoming more statistically minded. In the marine world, the mounting toll of disasters is making people more concerned; the economic factors of life are causing searching questions to be asked, e.g. Why must we open this out for inspection? Why cannot this be put back into service? etc. Lloyd's Register itself is committed to the analysis of failure and reliability studies in order to reduce the potential hazards of another *"Amoco Cadiz"* type incident.

If such studies are to be meaningful, then more information, rather than less will be required. Information about repairs which hitherto have been considered of little consequence will assume more importance as a picture of overall reliability of installations to be built in the future is assessed. The problem confronting the Society at the moment is how to gather this additional information. I think it is fair to say that less information is being volunteered by Outport Surveyors in the way of minor repairs; this point is made in paragraph 4.14 and 4.17 of the paper.

As stated in the paper, some 1,000 reports, ship and engine, are received weekly in headquarters, 400 of which contain useful information to T.R.O., i.e. 52,000 reports a year, over 31,000 of which give no defect information. Paragraph 1.5 refers to the massive feed back of information. May I suggest that this information is not sufficiently detailed and that the trend must be reversed. Referring to the words "damage and defect" part of the statistics allied to the studies you have seen tonight refers to the cause of damage for specified areas (general study). One item in that table is headed: "unknown/not stated". In the case of the hull, this averages about 50% of all cases and in the case of machinery 90% of all cases.

Given that for some damages the cause is obscure, it cannot be as high as the tables indicate. I suggest that to put a highly trained man in the field, an acknowledged expert, and then, because of underwriting interests, not allow him to state a cause is denying the Society the feed back which is its main source of information. The letter to the Chief Surveyors Records is practically non-existent. Is it not time a method was devised to circumvent this situation?

For the Engineer Surveyors there is now available a continuous monitoring of transmissions, and machinery studies are available for transmission, main and auxiliary engines, main and auxiliary turbines, gearing and main auxiliary boilers.

A general study of main oil engines since 1960 shows continuous trouble with crossheads and turbo blowers. These high numbers are not catastrophic, but if T.R.O. is to be used properly, should we not instigate action to reduce the incidence rate and should we not move to ensure that minor items are minor, and not just omissions of reporting. What is the point in recording defects for statistical purposes if it is not to improve performance. Only by refining the database, removing minor deficiences, and working to lower the high incidence rates will the data base be capable of undertaking the reliability studies the Society has in mind. There is no sense in keeping records on items which

have given no trouble in twenty years, but there are new areas which have become highly sensitive and we must turn our attention to them. On the problem of reliability, we need information in areas where previously no records have been kept, these too must receive attention.

Other studies now available show similar patterns. A reduction in high incidence rates and an improved feed back from the field Surveyors could do much to enhance the Society's reputation.

These studies are available to the Outports in a similar manner to the hull studies referred to in Hull Development Unit Rpt. No. 204.

In T.R.O., we should like to see the basic data gathered at the plan approval stage, some of this already goes to S.I.S. from technical departments but in so far as the L.R. classed fleet is concerned there seems to be a certain reluctance to move with the times. A first entry is handled in the Outport and at least three times in different head office departments, at present the method of disseminating information is such that it is possible for the R.B. & T.R.O. to have different figures for the same thing. I believe that the information for the Lloyd's Register classed fleet must come from a single source and I suggest it should be T.R.O. In that way, and that way only, will technical people be responsible for what information is fed to the Register Book. S.I.S. is receptive to such an idea. However, changing the habits of 200 years cannot be brought about overnight.

Doing it the T.R.O. way would eliminate duplication of effort, simplify the system, and produce first entries for the Outport Surveyor.

I would like to thank the Author for the considerable effort he and his colleagues have made in presenting the paper and trust this will lead to a greater understanding of the Department's work and what we should like to achieve as an integrated part of L.R.

From Mr. A. J. Smith:

This paper highlights the work of a Department whose efforts have received little acclaim and the Author is to be congratulated in bringing to our notice the fact that T.R.O. does more than just produce the Noteworthy Defect Lists. Quite rightly, the Author refers to the problems of interpretation when extracting details from Surveyors' reports. The matter of standardization in report terminology is one which is to receive attention shortly as it is realised that although many of our overseas colleagues speak and write English as well as we do, there is scope for guidance in the matter of description. It is thought that as the bulk of our new entrant Surveying Staff in the future will not have English as their native tongue, guidance on precise and accurate reporting becomes essential. This is perhaps not quite so important in Classification reports, where the Reports Department can always obtain clarification but in the matter of damage reports for Underwriters, Owners etc., we do not have the opportunity to amend or clarify the report before the document is handed over.

Hand written reports have been deplored for many years and perhaps it is time that this practice was finally discontinued. The typing of relevant sections in T.R.O. would make for clarity and a copy attached to the Classification Report, would be appreciated.

Reports 8 and 9 are Classification reports intended for the information of the Classing Committee, and usually the statement—"Minor repairs effected"—refers to work of little importance and of no significance in the matter of defect analysis. I suggest that such statements be disregarded by T.R.O. If, however, it is felt that more details are required, a note to this effect may be attached to the report for the attention of the Classification Reports Department who will take up the matter with the Surveyor.

I should prefer the words—'and defect'—be included in Standard Damage Analysis as 'damage' always implies Contact, Heavy Weather, Grounding, etc., but does not include those failures resulting from imperfections in design or construction.

It is noted that, in Fig. 12, half of the damages sustained by the sample fleet were 'cause stated unknown' and affected two-thirds of the ships. Are these proportions indicative of other parts of the ships as this would seem to negate the value of the breakdown? Is the incidence of damage ever related to specific Owners' fleets or Flags? The Underwriters would appear to have drawn their own conclusions. (Lloyd's List dated 21.9.79. states—" . . . high Loss Rate led London Underwriters to impose a 50% additional premium on cargoes carried in Greek ships over 15 years old").

Could the cause of damage be considered in the incidence listing, Fig. 13, as this could show up significant aspects of ship handling, e.g. Ship A has frequent contact damages —is there a pattern of inept ship handling? Ship B often suffers pounding damage to bottom plating forward—is the engine power sufficient to enable high speed to be maintained in adverse weather conditions? Do we receive a sufficient quantity of reports containing any reference to cargo damage having been sustained, enough to form any opinion of the quality of ship maintenance? Are such significant phrases as 'cross-joint bolts inoperable', 'fastenings freed', etc., recorded? May I suggest that they should be as the Society is sometimes involved with litigation of a cargo damage nature and once an A.S. and P.L.I. is finished it appears that closing appliances are often left to their own devices until the next survey is held. Once the survey is completed, of course, the matter of weathertightness becomes the responsibility of the ship's crew.

If, in such cases, the Society could show a history of inadequate ship maintenance, it would be of value in combating criticism.

The Noteworthy Defects List is good but severely hampered by restricted availability. Could not the contents be brought more easily to the Surveyors' attention without affecting the Confidential nature of the contents? Is it really necessary to publish ships' names if a record is kept in T.R.O.? A disturbing feature is the recurrence of similar failures year after year.

Errors in reporting should be referred to Classification Reports Department who, in their scrutiny of reports for classification, will take any necessary action.

In the matter of Classification procedures it would be interesting to hear the Author's views on refinement as this has been the subject of considerable debate within the Classification Department.

I should like to thank the Author for his admirable presentation of this interesting and informative paper.

From Dr. D. S. Aldwinckle:

The feedback loop for monitoring or control purposes in any organization is an essential, but often neglected, aspect of completing a cycle. In the Society, we often pride ourselves on the unique opportunity we have in recording full-scale service experience of at least one-third of the world fleet; but the importance of reporting, and the subsequent analysis of this service experience, should not be overlooked because it is germane to the Society's very existence and to the future service which we offer. With the Society being involved in extensive risk and reliability analyses, and with various Governments and communities being concerned at the number of marine incidents, the collection and analysis

of failure and accident rates are becoming even more relevant. The Author, T.R.O., and the Committee of the Technical Association are to be congratulated on presenting such a timely and important paper.

The last decade has seen a tremendous change in the types of marine structure. Extrapolating and interpreting service experience for novel structures were not entirely possible hitherto, and this gave rise to a significant development in more advanced direct calculation methods. This is not to say that the recording and monitoring of service experience for such structures should be ignored. On the contrary, it can be argued that it is now even more important. This is the main reason why the Hull Structures Department a few years ago took the steps to collaborate with T.R.O. to help make more effective use of the existing information in the database by producing output initially which would be readily assimilated and be immediately helpful once the novel structures went into service. It is also necessary to monitor new Rules, and such criteria as stress levels, which form part of our direct calculation methods. It is pleasing to see this effort taking up a large portion of the paper. It is also encouraging to see that this lead has been carried through into the machinery area.

I fully agree with the Author's statement on page 19 concerning the need for correct terminology. I will go further, and suggest that it should be consistent, and is so important that it might have been very useful to define this at the beginning of the paper under glossary of terms. For example, buckling is often confused with dishing of plates and vice versa. I think your definition of reliability needs amplifying because of the many definitions in existence.

There are a few questions I should like to ask on the paper itself, particularly the work of T.R.O. and the future. I am intrigued at ad-hoc enquiries (Section 6) being 'updated'. Perhaps you could explain this service because I do not recall receiving any updates! One point I feel needs further discussion is the statement that T.R.O. is processing around 400 reports each week. For the L.R. classed fleet of about 10,200 ships over 30 metres, this amounts to about 2 reports per ship per year. We have recently broken the 100 million gross tonnes mark, and it now stands at over 113 million. The number of reports to complete and analyse is increasing, therefore, all the time. I agree it is considered prudent to use all of the data available for a given ship type (para. 7.6), but what number do you consider small?

It is recognized that certain components over their lifetime follow a 'bath-tub' distribution of failure giving three distinct phases of life. An initial or shake down period, a middle or normal active period (with a constant failure rate or M.T.B.F.) and a final or wear-out period. Perhaps the Author could explain why M.T.B.F. cannot be accurately determined from the T.R.O. data, as discussed in para. 8.9. The U.K. Atomic Energy Authority offers a good service in this area, which I understand is increasingly utilised by another Classification Society.

In the future, it is recommended that there be greater discussion on the form of the analysed output, but more importantly, on what we need to gain from ship service experience. Recent studies for clients in the Hull Structures Department and elsewhere have shown that there is a need to specify more precisely the form and type of component failure data required, and our draft report (Ref. 5) is a start in this direction. Items which are repaired or replaced without consulting the Society's Surveyors e.g. those carried out at sea are also of interest. This will undoubtedly mean collecting more data, but it is very unlikely that this can be done for every ship. It is seen to be necessary, therefore, to establish an up-dated Society strategy and statistical analysis for such work to guide the excellent work of T.R.O.; otherwise we may make the mistake of simply collecting data for the sake of it. There is much for the Society to gain and, conversely, much which could be lost if we do not continue the efforts which have been made over the last few years.

From J. J. Stansfield:

I would like to say a few words in defence of the Outport Surveyor. Bearing in mind that many reports have to be written under the pressures of a heavy workload, the experienced Surveyor is aiming to give all the essential facts in the briefest text.

Therefore, the first point I would like to raise is the question of minor defects (para. 4.17). These are usually of minor importance often as a result of a lack of maintenance or an over enthusiastic use of paint and which, I would imagine, are of little or no interest to Technical Records.

Regarding the question of the type and cause of damages (para. 4.14). It is not possible for the Surveyor to state his opinion on the present report forms; except for a clearly defined incident recorded in the ship's logbook and which is subject to immediate survey, the term 'cause not stated' is often the only statement he can give. Although the Surveyor is instructed to write a separate letter to accompany the report in which he can express opinions, up to now there has been no clear explanation of how this extra information is used. This paper helps to explain how it is used, but if additional details are required the Surveyor should be convinced that they are an essential part of the report. May I suggest that the report forms be revised or additional sheets added, separate from the classification report, on which can be written in a prescribed manner the information required.

Referring to the Noteworthy Defect List (section 12), this is a most useful source of information which is usually under-utilized. In order to assist the Surveyor, could there not be a cross reference on the monthly microfilm or in the S.R.L. This would draw the Surveyor's attention to any entry in the N.D.L. for a particular ship. It is my view that there should be more feed back of data to the Surveyor and to show that the information in his report is of use, a separate note of the entry in the N.D.L. could be sent to the Surveyor whose report instigated the entry being made.

Finally I would like to thank Mr. Sullivan for a paper which enlightens us of the work of the T.R.O.

From Mr. L. N. Heminway:

As a result of questions raised during the discussion and in the written contributions, it is felt prudent to explain in detail the statistics used and the limitations imposed by the data in its present form. The limitations are:

i) incompleteness of the defect data. This should be improved and refined in the future, but meantime it is restrictive only because the full extent of a particular problem sometimes is not known.

ii) the actual time at risk for a ship is not known and it is unlikely that the time spent at sea will ever be available to the Society. This inhibits statistical manipulations of the data needed for risk analysis.

However, all is not lost as the following notes indicate.

The underlying philosophy in the continuous monitoring of defects lies with the analogy of quality control processes used in the manufacturing industries for determining the rate of defective goods being produced. Changes in an acceptable proportion of defective goods need to be detected.

Cusum techniques are a refined, and fairly recent, development in this area of statistics. The theory and application of this technique is set out in British Standard BS5703 entitled 'Guide to Data Analysis and Quality Control using Cusum Techniques'.

The application of this concept to the Society's defect data is explained in reference (2) listed in the paper.

The statistics produced from the stored data are defect counts occurring in fixed periods of time. The interest lies in estimating the mean rate of occurrence as well as looking for a trend or other systematic features in the incidence rate. The null hypothesis, i.e. initial assumption, is that the defects occur randomly in time at a constant rate. The mathematical model for dealing with this discrete situation is centred around the Poisson distribution. All of the significance testing, confidence limits and expected values are based on this model. The Poisson process is a mathematical concept and no real data can be expected to be exactly in accord with it. Whether or not a particular set of figures is in reasonable agreement with a Poisson process is ultimately an empirical matter. The main feature however, is its relative simplicity since the only parameter required is the incidence rate.

The exponential model is a continuous distribution used when considering the mean time between defects (failures). Only one parameter needs to be defined, the M.T.B.F., and this value is the reciprocal of the incidence rate, given that the period of risk starts from the date of build or renewal and ends with a defect. This model is rejected for our purposes because of the lack of information, as explained below, considering the time taken for the defect to occur and the time a ship is in operation.

Also the bath-tub curve mentioned in some textbooks on reliability is not relevant to our data—the theory was developed in relation to components such as electronic equipment where the failure rate is fairly high initially, followed by a constant, i.e. random rate of failure, and terminating in a wear out period. This non-relevance is because renewals or replacements due to a component being worn out are not recorded on the database, nor, in general, is there a high initial incidence rate.

The incidence rate and M.T.B.F. are not so much measures of reliability as measures of the frequency of a defect occurring. Reliability, which is the ratio of the number of items which performed their functions satisfactorily at the end of a stated period of time to the total number of items in the sample at the beginning of the period, is thoroughly dealt with in section 8 of the paper.

In our terminology, perhaps we are best guided by British Standard BS4778—Glossary of terms used in quality assurance (including reliability and maintainability terms).

A defect is defined as an incident having occurred and been reported on a given date. The Surveyor reports either a defect discovered during a routine survey or a defect due to an incident which occurred on a known date and is usually operator caused. In the case of non-operator caused defects, the precise date of occurrence is rarely known.

The count of incidents is related to the enquiry and can be, say,

i) the number of ships lost.

ii) the number of damages sustained to the aft end of a specific ship or a number of ships.

iii) the number of defects in the aft peak tank.

The latter two examples need to be defined from a variety of standpoints such as:

i) does the aft end include the rudder.

ii) are all types of defect to be included or confined to, say, fracturing.

iii) are all types of cause to be included or only those stated to be non-operator caused.

iv) how is the final count to be made; by date of reporting, area of ship, space, component, item, type of defect or cause—or any combination of these variables.

The extent of damage can be determined by combining the appropriate defect count variables mentioned in (iv) above, but the severity of damage cannot be ascertained from the data in its present form. The defect count for the hull general and area studies as well as the hull monitoring is by space and item for each defined area. For the

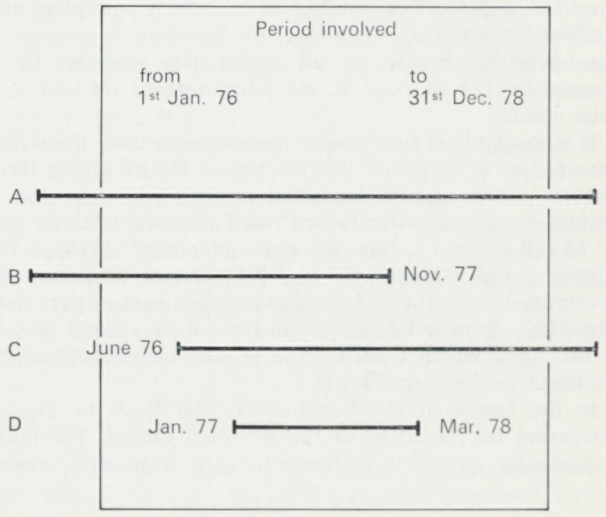


FIG. A

machinery general study, area studies and transmission monitoring the count is by component and location for each machinery area.

The aggregate years or months service relate to all the relevant engines or hulls at risk whether they have reported defects or not. The time at risk which spans from the date

of build to the date of disclassing excludes known lay-up periods and is related to the calendar period of the investigation.

This can be shown diagramatically as follows in Fig. A.:

The aggregate service for A, B, C and D, is (36+23+30 +14)=103 months. For the convenience of the database structure, dates of build and disclassing are considered to occur at the end of the month. Although lay-up time can be deducted from the aggregate service, no allowance can be made for time spent in port or under repair. However, time involved while a ship is being converted is not included in the aggregate service.

The incidence rate (I) is defined as the ratio of the number of defects (d) to the aggregate years or months service (t) of all the relevant engines or hulls at risk for any given time period whether calendar or service age.

I which equals $\frac{d}{t}$, is multiplied by 100 for the convenience of quoting the resulting figure in units and is therefore expressed as 'per 100 years, or months, service. The incidence rate could equally be expressed as 'times 10^{-2}.

e.g. $I = 0.086$

$= 8.6 \times 10^{-2}$

= 8.6 per 100 years or months.

The interpretation of this rate is varied and depends on the time period considered as well as the component or structure being studied. In general, the rate of defect is assumed to be constant and so an incidence rate of 10 per 100 years service means:

i) a ship can expect one such defect in 10 years service.

ii) ten ships out of 100 can each expect one such defect in a calendar year.

iii) a total of ten defects can be expected from 10 ships in a period of 10 calendar years.

A given overall incidence rate is simply a quantification of what has occurred and, in general, is an acceptable rate. It shows how different components relate to each other. At this stage, overall reliability of the hull or machinery can be improved by concentrating on those components with the highest incidence rates. For a particular component, emphasis should be placed on those designs with a higher than average incidence rate for that component.

In making comparisons, care should be taken not only in comparing like with like, but, particularly, in relation to size and age. Generally, as size increases so a ship spends more time in operation but the denominator of the incidence rate is in calendar time. It follows that increasing incidence rates with size may not be a true reflection of defect rates.

Age is important because of survey periods. If a certain defect is generally only found at, say, quadrennial surveys then it is not correct to compare a group of ships only three years old with a group five years old. However, analysing the data by service year as shown in the following section is of value.

The incompleteness of some of the data does not invalidate comparison between groups as the assumption is that in general no one sub-group is more under-reported than the others with which it is being compared; also a similar pattern in the incidence rates over the service life of the ship and its machinery is assumed, until shown to be otherwise. A standard program has been developed to calculate the incidence rate for each service year, as well as the cumulative incidence rate. Table 1 shows an example of defects counted by date of reporting to a given hull area in ships over 90 metres in length during 1977 and illustrates peaks of non-operator caused damage, while operator caused damage is random and fairly constant over time.

Service year	No. of defects		years service	incidence rates	
	non-op	operator		non-op	operator
1st	11	15	306	3.6	4.9
2nd	15	16	255	5.9	6.3
3rd	14	12	229	6.1	5.2
4th	30	10	240	12.5	4.2
5th	46	19	272	16.9	7.0
6th	18	7	244	7.4	2.9
7th	19	16	221	8.6	7.2
8th	17	13	212	8.0	6.1
9th	23	11	218	10.5	5.0
10th	27	6	198	13.7	3.0
11th	13	11	199	6.5	5.5
12th	15	5	175	8.6	2.9
All	248	141	2769	9.0	5.1

TABLE 1

	No. of defects	Ship Years	Incidence	Confidence Limits of incidence
A	60	500	0.12	0.09 to 0.15
B	16	200	0.08	0.05 to 0.13

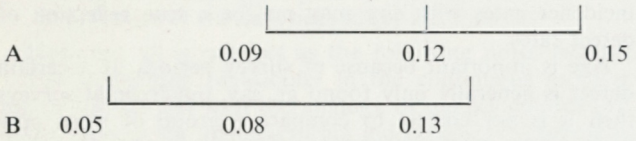
TABLE 2

The incidence rate is also used for comparing the performance between two or more groups. Here the calculation of the confidence limits (C.L.) discussed in paragraph 7.20 of the paper is important. The 95% C.L. of an incidence rate is calculated as lying between

$$\frac{d+2-(2\times\sqrt{d})}{t} \quad \text{and} \quad \frac{d+2+(2\times\sqrt{d})}{t}$$

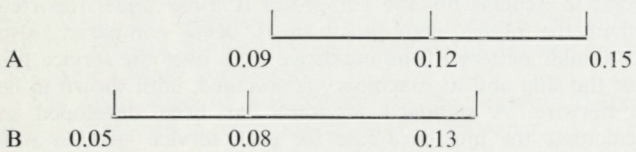
When using the confidence limits to compare the difference statistically between incidence rates, what is being measured needs to be carefully defined as the significance can be approached in three ways. Table 2 refers:

i) Does group 'A' have a higher incidence than group 'B'—this occurs when the incidence of "A" lies beyond the confidence limits of "B"



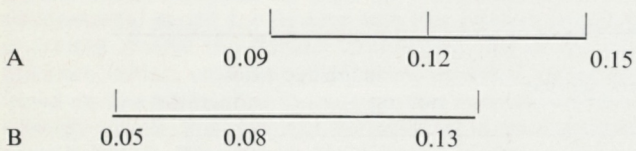
Answer—NO

ii) Does group 'B' have a lower incidence than group 'A' —this occurs when the incidence of 'B' is less than the lower confidence limit of 'A'



Answer—YES

iii) Do the incidences of groups 'A' & 'B' differ—this occurs when the upper and lower confidence limits respectively do not overlap.



Answer—NO

The above examples show that apparent contradictory statements do sometimes occur.

The total number of defects in a sub-group is related to the aggregate ship years in the main group and if there is no difference between the incidences of different sub-groups, then it is to be expected that each sub-group would have the number of defects proportional to their aggregate years service. There will be differences between the reported and expected defects and these can be tested for statistical significance.

In Table 3 below the main group is represented by the total and the sub-groups by each service year. An increasing defect rate through age is indicated.

	Service year 1	2	3	4	5	Total
Years service	167	133	100	67	33	500
Reported defects	12	12	12	12	12	60
Expected defects	20	16	12	8	4	60

TABLE 3

The range of the expected number of defects can be calculated as a variation of the confidence limits. The expected number for each sub-group in Table 4 below is based on the other sub-group being studied.

	Number defects	Ship years	Range of expected defects
A	16	250	23 to 45
B	64	500	23 to 45

TABLE 4

The inference is that A has less defects than expected compared with B, while conversely B has more defects than expected compared with A.

The incidence rate is the standard measure of the frequency of damage. However, this measure does not relate the degree of damage for a particular ship or sub-group to the fleet or main group as a whole.

The probability of failure rating, used in the general studies and incidence lists calculates the probability of the incidence for any ship, or sub-group in relation to the average incidence for all ships in that fleet or main group.

In general the probability rating is inversely related to the incidence rate but allows for instances of zero defects when the incidence rate cannot be calculated.

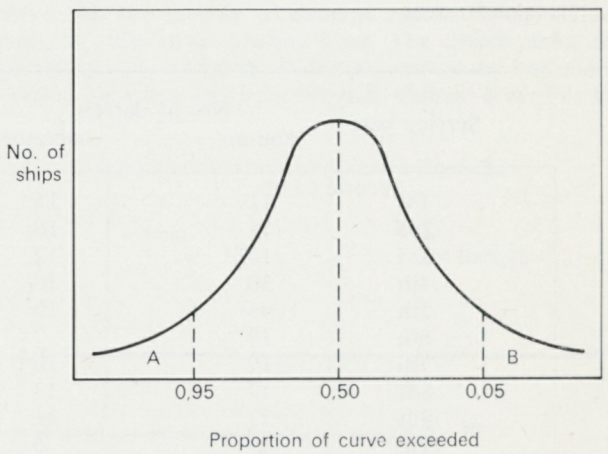


FIG. B

In Fig. B above, ships or sub-groups with a probability rating falling in space A (that is, greater than .95) have at least a 1 in 20 chance of not being better than the others, while those with a probability falling in space B (that is less than .05) have no more than a 1 in 20 chance of not being worse than the others.

Spaces A and B can be varied in size to suit any particular enquiry and thus limit the number of extreme ships to be studied in detail. It should be noted that the normal curve is symmetrical and its area is taken as unity. The probability values lie between 0 and 1 and cannot equal them.

When a fleet does not conform to the theoretical frequencies, the reason can be attributed to any one or more of the following:

i) the fleet may not be homogeneous

ii) a large number of ships may have only reported minimal damage which is not a true reflection of the damage sustained by them. This would have the effect of lowering the overall incidence and increasing the number of apparently bad ships.

iii) a number of ships may have experienced an exceptional amount of damage.

The count of damages can be represented by the Poisson distribution. The probability of damages is determined from the formula:

$$P(r) = \frac{e^{-m} \cdot m^{r}}{r!}$$

Where m is the ratio of the total number of damages to the aggregate months service. When multiplied by 100, m is known as the "Incidence per 100 months Service'.

The formula can be re-arranged so that for a given period of service, the probability of the stated number of damages being exceeded, when compared with the average, can be calculated. The formula is:

$$P(\text{more than } r) = 1 - \sum_{r=o} \frac{e^{-tm}(tm)^{r}}{r!}$$

Where t = given period of service m and r are as defined above.

The probability of a stated number of damages being exceeded lies between 0 and 1. The closer the calculated value is to zero, the smaller the chance of the stated number of damages being exceeded for the given period of service. The inference is that those ships with the lowest value have the worst record.

In determining the statistical significance between two incidence rates, the following applies:

$m_1 - m_2 = \frac{d_1}{t_1} - \frac{d_2}{t_2}$ is an unbiased estimate of

$(m_1 - m_2)$ and an unbiased estimate of its variance is

$$\text{var}(m_1 - m_2) = \frac{d_1}{t_1^2} + \frac{d_2}{t_2^2}$$

hence the test statistic, which when d_1 and d_2 are large can be treated as a standardised normal deviate, is:

$$\frac{\frac{d_1}{t_1} - \frac{d_2}{t_2}}{\left(\frac{d_1}{t_1^2} + \frac{d_2}{t_2^2}\right)^{\frac{1}{2}}}$$

It seems likely that this statistic has good properties even when d_1 and d_2 are quite small because $(m_1 - m_2)$ has a distribution quite close to normality and because the fluctuations of the estimated variance around the true variance are relatively small.

The statistical difference in the ratio of two incidence rates is determined by considering the logarithms of these rates.

$$\text{Standard Deviation } (\ln m) \simeq \frac{SD(m)}{m}$$

$$= \sqrt{\frac{d}{t}} \cdot \frac{t}{d}$$

$$= \frac{1}{\sqrt{d}}$$

The test statistic becomes

$$\frac{\ln m_1 - \ln m_2}{\sqrt{\frac{1}{d_1} + \frac{1}{d_2}}}$$

It should be noted that the standard deviation of the log incidence rate is independent of the numbers at risk and the time interval.

Testing for trends in the incidence rates by, say, service years is carried out by calculating

$$\frac{[\sum x(d-e)]^2}{\sum ex^2 - (\sum ex)^2/\sum d}$$

where x = service year

d = defects in service year

e = expected defects in each service year calculated as

$$\frac{t\sum d_i}{\sum t_i}$$

t = total service in a service year.

This value is compared with the relevant figure from the chi-squared table in order to determine its significance.

The minimum sample size required for any valid inference is dependent on the number of defects recorded and the 'true' incidence.

The formula for the calculation of the confidence limits is unstable when the count of defects is less than six. The lower confidence limit for this value is three.

From experience, the incidence rates, in general, range between 0.01, i.e. 1 per 100 and 0.1 i.e. 1 in 10.

Table 5 below shows the minimum aggregate time in service required for any valid inference to be made from the resulting incidence rates.

'true' incidence	minimum aggregate time
0.01	300
0.02	150
0.05	60
0.10	30

TABLE 5

Other statistical techniques used for analysing the data include:

i) regression analysis

ii) contingency table analysing using log-linear techniques.

iii) calculation of moments and distribution parameters.

From Mr. B. Rapo:

Mr. Sullivan's main emphasis regarding the need to draw attention to the type of service offered by the Technical Records Office is considered to be justified.

The wealth of valuable technical data contained in the Society's archives serves little useful purpose unless potential users are fully aware of its existence.

In initial design work, one of the fundamental parameters is the steelweight estimate and lightweight breakdown. It is unfortunate that our system is not geared towards collation of this type of data. It is appreciated that the Builders in most cases jealously guard such information, being fully aware of its commercial value, but when approached by non-commercial organizations, the Builders

have usually been found willing to supply this type of information. It is certain that apart from lightweight data, there will be numerous other aspects which could be raised. Perhaps a revision of the present scope would offer service of even wider interest.

The Author of the paper is to be congratulated on presenting a very useful paper.

From Mr. K. O. L. Nilsson (Gothenburg):

Mr. Sullivan has written a most interesting and comprehensive paper about the work in his Department, and I would like to congratulate him on a splendid result. It is indeed interesting to follow the development by comparing this paper with Mr. G. M. Boyd's on the same subject twelve years ago. Remarkable progress has taken place simultaneously with improved processing techniques, but should not the next step be to dispense with punched cards entirely and, by using special computerized questionaires, feed the information directly into the computer? Further, I am not clear whether the basic data is the same as that used for the Register Book. If they are the same would it not be possible to have only one file instead of two?

When the Author states that his Department is "not as well known as might be wished" I think at least part of the explanation can be found under para. 9, Regular Bulletins. Here the Author says: "These (the regular bulletins) are confidential and only issued to Principal Surveyors and above." Who is interested in a Department and in collecting data for this Department when it is specifically emphasized that the collector does not qualify for seeing the result of his efforts? In my opinion the Technical Records Office should turn to as many Surveyors, Clients and learned Societies, etc. as possible and by publishing selected information make the potential of this Department known as widely as possible, of course without passing the borderline of confidentiality and integrity. A consultancy firm in Sweden, connected to a big shipowner, who has up to now classed all ships with this Society, has set up a data bank of ship failures. We will not be beaten by the amount of information, and we should make sure we are not beaten at all. I find it most disturbing that our Clients consider it advantageous to build up their own records in this field.

Reliable input data is most important for accuracy. At least one other Classification Society makes use of Chief Engineers for collecting data which would not otherwise be received. For instance renewal of minor electric or electronic details of special importance. Why not turn to Owners and Underwriters for further information?

The Author has not discussed the fact that the Instructions to Surveyors asks for the stated cause of damage, which is not necessarily the same as the real cause. In my opinion this may be a further limitation to the data storage. It is pointless to ask for additional information in one paragraph when another one forbids you to express your own opinion!

In a technical language the cause of a failure may be for instance brittleness, fatigue, yielding, etc., but not heavy weather, contact, grounding, etc. Furthemore, these latter causes have nothing to do with the reliability of the construction, and I am not clear how you separate the different causes.

I would also like to ask if the information collected is sufficiently accurate for permitting statistical comparative studies of failures from a metallurgical point of view? In my experience the real cause may be revealed first under the microscope, but very few such investigations are made.

From Mr. C. L. Foo (Taipei):

Many thanks to the Author for a very informative and excellent paper. It gives me considerable pleasure when explaining the high cost of L.R. survey fees to local Owners, Builders and Manufacturers by describing to them the many non-fee earning services in which L.R. is involved, for the good of the marine community as a whole.

Referring to 10.2 of the paper, it is noted that no reference is made to Reports 10 throughout the paper. This port carries out a considerable number of damage surveys on behalf of the Salvage Association involving ships classed with other Classification Societies. Are these reports of any use to T.R.O.? Perhaps other ports are similarly involved, in which case would not the figure of 30% be increased?

From Mr. R. J. Sullivan:

I would like to add my congratulations to the Author for a very informative paper. He certainly highlighted many aspects of T.R.O. which were unknown to me.

Now that we are aware of what is available from T.R.O., I hope, in practice, that not only Outports and Owners will be able to gain access to pertinent data in the shortest possible time but also departments within H.Q. This, I feel would assist the Plan Approval Surveyors in their day-to-day decisions, which quite often lie within the "grey" areas of Rule requirements.

During the presentation of the paper, mention was made of a Table used in T.R.O. to verify the principal dimensions of ships. It would be of some interest to see a copy of this table in order to compare it with the example of a validation check, as shown in Fig. 6.

Reference is made on page 8, section 4.12 to the coding of significant defects or damages. Perhaps an extract from a coding book and an example of a completed coding sheet could be given to indicate the procedure followed.

From Mr. M. B. Leese:

On many (if not most) occasions when reporting damage, the Surveyor is obliged to supplement his description with the phrase "stated to have been caused by . . . " for traditional reasons of non-prejudice. Every Surveyor at some time must have come across a damage which his experienced eye tells him is not attributable to the cause which the Master, Chief Engineer or Superintendent insists on giving him. The Surveyor's only way of giving his opinion in such circumstances is a letter to his Chief, but presumably this information does not find its way back to T.R.O.

In a case like this it would seem that T.R.O. can only record false information. Our colleagues in that Department appear to be faced with two choices: either to record the stated cause of damage, with the risk that it may be wrong, or to record the case as "unknown". Either way, the credibility of any statistics retrieved at a later date must inevitably suffer, and to have to record a large proportion of damages as being of "cause unknown" (p. 14, fig. 12 of the Paper) negates the whole concept of the T.R.O. damage statistics retrieval system.

I would appreciate the Author's comments on this aspect of his very informative paper.

AUTHOR'S REPLY

Initially I would like to take this opportunity of thanking all those colleagues who have contributed to the discussion.

To Mr. R. M. Leach:

I would like to thank Mr. Leach for his valuable comments, especially those concerning Classification Reports.

I would agree with him that it is difficult to interpret fully the statistics contained in many T.R.O. investigation reports if one is not a statistician. However, Mr. L. N. Heminway's contribution is of assistance in this respect, where he explains more fully some of the statistical methods used.

To Mr. G. J. Talbot:

To overcome the lack of detailed information, T.R.O. have produced an appendage to the Report 9 for discussion with Machinery Reports in an attempt to solve this problem.

Nevertheless, the dates of operator-caused damage to the hull (i.e. collision, contact, stevedore, etc.) are usually known, whereas the dates of non-operator caused types of damage (i.e. heavy weather, pounding, sloshing, etc.) are usually unknown, especially when they occur within a confined space. The results of non-operator caused types of damage are usually found during classification surveys and are very often reported as "cause and date unknown/ not stated". With this type of damage, whilst it is important to know when, it is more important to know where and to what extent, and if considered significant, amendments are made to the relevant sections of the Rules. This is equally applicable from the machinery viewpoint.

Although some letters do reach T.R.O. direct, the majority are sent to the department most directly involved. After consideration by the respective departments, T.R.O. usually becomes involved if, and when, an investigation is carried out, and is then requested to supply data in simple or analysed form. It is considered in T.R.O. that any letters sent for the Chief Surveyors Records should at all times be sent directly to T.R.O., who would then forward a copy to the respective department involved. With this system, T.R.O. would have access to all available information when requested to investigate a particular problem.

Minor defects are of little importance in themselves, if that is what they really are. Where one has to be careful is when the type of defect which requires little effort to repair, but could, if left, propagate into something considerably more serious. It is this type of defect which could be, and often is, included under the umbrella of "minor repairs affected", and if the Society is to become more involved in reliability studies, it is essential that we define what is meant by the word minor.

The refining of the hull and machinery database (Basic and Defect) is an on-going process and whilst the system is not perfect, it is considered sufficiently accurate to carry out reliability, or any other type of study, outlined in the paper.

It must be said, however, that T.R.O. would like to see at least the present amount of data compiled at a much earlier date and this could be achieved by producing data sheets, some of which would be pre-coded, for completion during the plan approval stage. It is envisaged that these data sheets would contain about 95% of the present coded information. On completion of the ship, the Outport Surveyor would send his First Entry Report to Headquarters in the normal way, together with the up-dated coding sheets. After processing, the Surveyors in First Entry Department would complete a single data sheet giving the missing 5% of information (e.g. tonnages, details of equipment, etc.) They would then send the complete set of data sheets to T.R.O. who would process the missing 5% and any amendments which may have been made during construction. The benefits of this procedure are as follows:

i) approx 95% of all coded information would be on record and available for use considerably earlier than at present.

ii) it should be more accurate.

iii) it would eliminate basic data cards which at present are processed on three separate occasions. Furthermore, it is my opinion that these cards no longer adequately perform the function for which they were designed.

iv) the inclusion of a separate sheet giving permissible deck loads could be microfilmed and the information would normally be available within minutes of a request for this information being received instead of hours or days under the present system.

Furthermore, I also agree that responsibility for the accuracy of information fed to the Register Book should come from T.R.O. via Plan Approval Centres and Outport Surveyors as outlined above.

To Mr. A. J. Smith:

I fully endorse Mr. Smith's comments concerning the standardization of report terminology and any attempt to do this would receive the full backing of T.R.O.

Standard damage analysis is a general term intended to cover all aspects of defect data. It should be pointed out that damage is the effect, whereas heavy weather, grounding, etc. are the cause. Failure as a result of imperfections in design or construction produce precisely the type of information which results in Rule amendments.

Owner orientated investigations, which include the incidences of damage, are carried out as detailed in the paper under 5.6. Similar investigations comparing ships registered under one flag against another are not carried out. However, T.R.O. does not specifically investigate an Owner's fleet without his specific request.

With reference to the cause of damage shown in the incidence lists, Fig. 13 only considers groups of ships and is part of the monitoring process. Investigation into the performance of individual ships compared with other similar ships can be dealt with on an "ad hoc" basis. There is no standard procedure for dealing with this type of problem. Furthermore, T.R.O. does not receive any information on damage to cargo and only codes classification items.

Also, defects to securing arrangements on hatch covers are coded, but items such as "fastenings freed, etc." would appear to come under the heading of "minor repairs effected" and are treated as such. If the information was available and instructions given to record this type of defect, T.R.O. could include it in the system.

Regular Bulletins have been produced in preliminary form, but to-date have not gone into full production.

It is considered necessary to have any Noteworthy Defects for any given ship readily available in the outports, so that when a Surveyor is requested to attend on board a ship, for whatever survey, he can examine the subject item, if and when the opportunity presents itself, without recourse to Headquarters.

On the subject of under-utilization and non-availability, a system which worked extremely well in Antwerp was for the person responsible for the "work book entries" to be also responsible for keeping the Surveying Staff informed when any ship included in the N.D.L. came under survey in the port. This worked particularly well for the Surveyors who received most of their requests for survey whilst already in the docks.

When errors in reporting occur, which prevent detailed coding, they are usually errors of omission. A further aspect for refining classification procedures worth considering is first entry reports, which combine the requirements of classification with those of T.R.O. including the addition of some elements of the T.R.O. coding systems.

To Dr. D. S. Aldwinckle:

Consideration was given to the inclusion of a glossary of terms, but it was found to be too difficult to separate items such as buckled, bent, distorted, bulged, etc. It is a fact that Surveyors use different terms to describe the same conditions and it is with this in mind that T.R.O. grouped all types of defects under eleven headings for hull and machinery.

Surveyors and Clients often request that previous ad-hoc enquiries and investigations be brought up to-date whilst employing all the other original parameters. These results are therefore not for general distribution.

The computer database is an historical file and currently contains information on 10,500 propelled ships which have been built to L.R. class, but the number of propelled ships built since 1960 and currently in L.R. class is 7900. However, whilst the tonnage is increasing, the number of Reports 8 and 9 are not, as there is an optimum number of ships to L.R. class at any given time.

The question of smallness relates to a homogeneous subgroup which is being monitored or investigated on an ad-hoc basis.

It is understood by T.R.O. that Hull Structures Department has recently gained experience in the form and type of component data required in the application of stored data for standard damage analysis and T.R.O. is always prepared to discuss any proposals to improve the analysed output.

T.R.O. have encountered difficulty collecting more data and now consider that the best approach to this problem would be to refine the existing data collecting system.

Due to the delay in introducing a more clearly defined comprehensive strategy T.R.O. does collect a certain amount of extraneous information on the off chance that it may be required "sometime in the future". The time and effort required to process this information could be utilized more productively.

To Mr. J. J. Stansfield:

With regard to the Noteworthy Defects List, after consideration of all the factors involved, it has been decided to continue with the present format. By the time a final decision has been made to include details of a particular ship in the N.D.L., very little time elapses before the Outport Surveyor would be able to see for himself that it has been included.

To Mr. L. N. Heminway:

As Mr. Heminway's contribution is in the form of an appendage to the paper, his comments require no formal reply. However, I would like to express here my gratitude to him for his most valuable contribution, which has undoubtedly enhanced the paper.

To Mr. B. Rapo:

The subject of steelweight is mentioned under 11.2 of the paper. A discussion document was produced by T.R.O. in January 1976, which also includes details on lightweight breakdown, but to-date no action has been taken on the subject.

To Mr. K. O. L. Nilsson:

A document was produced four years ago in the form of a pre-coded questionnaire and was intended to replace the Basic Data Cards currently completed by the First Entry Department. These are first checked and coded by T.R.O. then punched and finally fed into the computer. The next step could be to eliminate the punch card by keying in the pre-coded questionnaire directly to the computer by means of a terminal, but unfortunately, T.R.O. does not have this means of processing information at its disposal.

Unfortunately there is a duplication of data, but T.R.O. processes considerably more technical information than that printed in the Register Book. It is realistic to have more than one computer file for output requirements but the source of input to these files should come through T.R.O.

T.R.O. have had discussions with Owners on the subject of establishing a data bank of ship failures, and is prepared to produce a printout of a standard damage analysis for an Owner, so that the Owner and the Surveyors may relate procedure with actual results.

As stated previously, the renewal or repair of minor items, e.g. electric and electronic, are usually reported under the umbrella of Minor Repairs Effected, if indeed they are reported at all; and until a decision is taken to define what is, or is not of minor importance, major problems will be encountered in the field of reliability studies. On the subject of acquiring further information from Owners and Underwriters, the Society is currently investigating this possibility with Owners.

I agree that the stated cause of damage is not necessarily the actual cause, but as advised by Mr R. M. Leach in his contribution, we are only permitted to report the facts as stated by the Owner or his representative. If the Surveyor disagrees with this statement, he may write a letter for the attention of the Chief Ship/Engineer Surveyors' Records giving the reasons for his disagreement with the stated cause.

It is appreciated that damage caused by contact, grounding, collision, etc., have little to do with the reliability of the hull, but a record is kept of them and they can be readily isolated from the non-contact causes of damages. For consistency, the causes/circumstances have been separated into the two undernoted categories:

Non-Contact	**Contact**
Pounding/Slamming	Collisions
Excessive Internal Pressure	Grounding/Submerged Object
Vibration	Damage sustained by ice
Wear and Tear (for ship's first 5 years)	Shift of Cargo
Sloshing/Free Surface	Cargo Handling
Heavy Weather	Mooring
	Contact
	Fire/Explosion
	Flooding

The coding of contact causes of damage still has its merits as T.R.O. is occasionally requested to investigate, for example, the number of ships of a certain deadweight and age range which have grounded, or the number of large tankers sustaining explosion damage in cargo tanks.

The information received in T.R.O. is basically that which is reported on the Reports 8 and 9, and is usually deficient in content to make any statistical study from a metallurgical point of view. It is anticipated however, that the Surveyors in Ship/Machinery Reports Department would refer anything of this nature directly to the Material and Quality Assurance section of R.A.T.A.S. for their consideration.

To Mr. C. L. Foo:

Only about 10% of all Reports 10 actually reach T.R.O. and are used to supplement the information contained in the Reports 8 and 9 when considered necessary. T.R.O. only processes ships classed with Lloyd's Register, therefore, Reports 10 giving details of damage to ships classed with other Classification Societies would not be of any practical use.

To Mr. R. J. Sullivan:

To comply with your request typical examples of a table verifying the ship's dimensions, a coding book extract, and a completed coding sheet are shown in Figs. C, D and E respectively.

To Mr. M. B. Lease:

The implications of Mr. Leese's comments concerning the credibility of the T.R.O. damage statistics retrieval system, if that system is supplied with either false or insufficient information, are fully appreciated and I would refer him to my reply to Mr. Talbot where this same problem has been considered.

Decision table

Ratio	Length ranges in hundreds											
	<1	1-	2-	3-	4-	5-	6-	7-	8-	9-	10-	11-
<7	A											
7-	A	W										
8-	A	W										
9-	A	A	W									
10-	A	A	W	W	W							
11-	A	A	W	W	W							
12-	A	A	W	W	W							
13-	W	A	W	W	W	W	W					
14-	W	A	A	W	W	W	W	W	W	W	W	W
15-	W	A	A	A	A	A	W	W	A	A	A	A
16-	W	A	A	A	A	A	A	A	A	A	A	A
17-	W	A	A	A	A	A	A	A	A	W	A	W
18-	W	A	A	A	A	A	A	A	W	W	W	
19-	W	W	W	W	W	A	A	A	W			
20-	W	W	W	W	W	W	W	W	W			
21-	W	W	W	W	W	W	W	W				
22-	W	W	W	W	W	W	W	W				
23-		W	W	W	W	W	W	W				
24-		W	W	W	W	W	W					
25-		W	W	W	W	W	W					
26-		W	W	W	W	W	W					
27-		W	W	W	W	W						
28-		W	W	W	W							
29-		W	W	W								
30-50			W	W								
50+												

A = accept

W = accept, but put message on printout
WARNING, DIMENSIONS MAY BE WRONG

blank = reject and put asterisks under dimensions.

FIG. C

762/DIC/001 JAL HULL DEFECT CODE COMBINATIONS. PAGE 2

03 TWEEN DECK SPCE		03006 WEB FR/PLT/TRAN
		03008 STGR/H.GDR
		03009 GIRDERS
		03012 STIFFS INC BKTS
		03029 LONGS
	031 SDE SHELL STRUC	03101 PLATES
		03104 SHEERSTRAKE
		03105 FRAMES
		03106 WEB FR/PLT/TRAN
		03108 STGR/HORIZ GDR
		03129 LONGS
		03137 BEAM KNEES/BKTS
	034 TRANSVERS BLKHD	03401 PLATES
		03406 WEB FR/PLT
		03408 STGR/H.GDR
		03409 GDR CON
		03412 STIFFS INC BKTS
	035 LONGITDNL BLKHD	03501 PLATES
		03512 STIFFS INC BKTS
	036 TRANSVERS STRUC	03609 DEEP/H.END BEAM
		03610 BEAMS
		03616 PILLARS
	037 LONGITDNL STRUC	03709 GIRDERS
04 TOPSIDE TANKS	040 UNSPECIFIED	04001 PLATES
		04006 WEB FR/PLT/TRAN
		04008 STGR/H.GDR
		04009 GIRDERS
		04012 STIFFS INC BKTS
		04023 WASH BHD
		04029 LONGS
	041 SDE SHELL STRUC	04101 PLATES
		04104 SHEERSTRAKE
		04105 FRAMES
		04106 WEB FR/PLT/TRAN
		04108 STGR/HORIZ GDR
		04129 LONGS
		04137 BEAM KNEES/BKTS
	044 TRANSVERS BLKHD	04401 PLATES
		04406 WEB FR/PLT
		04408 STGR/HORIZ GDR
		04409 GDR CON
		04412 STIFFS INC BKTS
		04423 WASH BHD
	045 LONG/SLOPG BHD	04501 PLATES
		04509 GIRDERS
		04512 STIFFS INC BKTS
		04517 BDT.BKTS/FLOORS
		04523 WASH BHD
	046 TRANSVERS STRUC	04606 WEB FR/PLT/TRAN
		04610 BEAMS INC DEEP
	047 LONGITDNL STRUC	04709 T.TOP/DK GDR
		04729 T.TOP/DK LONGS
05 P.B F SPACE	050 UNSPECIFIED	05000 WHOLE COMPONENT
		05001 PLATES
		05005 FRAMES
		05007 DOORS NOT SHELL
		05012 STIFFS INC BKTS
		05029 LONGS
	051 SDE SHELL STRUC	05101 PLATES
		05104 SHEERSTRAKE
		05105 FRAMES
		05106 WEB FR/PLT/TRAN
		05107 DOORS
		05108 STGR/HORIZ GDR
		05114 STEM PLATE/BAR
		05122 HWSE/SPURLG PPS
		05129 LONGS
		05137 BEAM KNEES/BKTS
	054 TRANSVERS BLKHD	05401 PLATES
		05407 DOORS NOT SHELL
		05412 STIFFS INC BKTS
	055 LONGITDNL BLKHD	05501 PLATES

DEFECT
01 = INDENTED/SET IN

REPAIR
06 = TEMP.

CAUSE
01 = COLLISION

Fig. D

TRO HULL DEFECTS

HULL IDENT	LR NUMBER	TR TYPE	DATE OF DEFECT YR MO	SECTION	SPACE or COMPNT	No of SPACES AFFECTED	COMPNT	DEFECT 1 ITEM	DEFECT 1 MATL	DEFECT 1 DEFCT	DEFECT 2 ITEM	DEFECT 2 MATL	DEFECT 2 DEFCT	DEFECT 3 ITEM	DEFECT 3 DEFCT	REPAIR	CAUSE OF CRACK	SPECIAL CASES	STATE	MICROFILM No	DATE OF MICROFILM YR MO	DATE OF DISCLASS OF SHIP YR MO	SHIP NAME
1 3	4 10	11	12 15	16	17 18	19 20	21	22 23	24 25	26 27	28 29	30 31	32 33	34 35	36 37	38 39	40 41	42 45	46	47 52	53 56	57 60	
H30		I	7906	29	2	02	9	01		01	17		01			06	02		1	B03	7909		
		I	7906	20	01	01	3	01		01						06	02		1	B03	7909		
		I	7907	58	2	01	1	01		01	29		01			07	01		1	A05	7909		
		I	7907	52	3	01	00	1		01						07	1	4	1	A05	7909		
		I	7907	51	9	01	00	1		01						07	1	4	1	A05	7909		
		I	7804	28	5	02	2	01		01						07	02		9	A06	7909		
		I	7905	20	1	02	1	01		01	06		01	05	01	06	01		9	A01	7909		
X		I	7905	24	4	02	1	01		01	06		01	37	01	06	01		9	A01	7909		
		I	7905	20	4	02	5	01		01						06	01		9	A01	7909		
		I	7905	24	4	02	1	29		01						06	01		9	A01	7909		
		I	7907	31	0	01	1	01		01						01	99		9	C06	7909		
		I	7906	58	2	01	4	01		01						01	99		9	B08	7909		
		I	7906	51	0	01	4	01		01						01	99		9	B08	7909		
		I	7907	48	3	01	1	01		01	01		03	29	01	01	01		9	B10	7909		
		I	7907	48	3	01	4	01		01						01	01		9	B10	7909		
		I	7908	22	01	01	1	04		01	04		05			06	01		1	B05	7909		
		I	7908	22	20	01	00	1		01	01		05	33	05	06	01		1	B05	7909		
		I	7908	16	00	1	1	00		1	3					07	1	2	9	B09	7909		
		I	7908	16	00	1	2	00		1	3					07	1	2	9	B09	7909		
		I	7908	28	3	01	1	04		01	04		05			07	1	4	2	B10	7909		

Form 3766A(4/76)

Fig. E

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BEP

Lloyd's Register Technical Association

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THE STAFF TRAINING PROGRAMME — 1979

R. S. Cornwell

Paper No. 2. Session 1979-80

FOR PRIVATE CIRCULATION AMONGST THE STAFF ONLY

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Hon. Sec. D. T. Boltwood
71 Fenchurch Street, London, EC3M 4BS

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FOREWORD

THE ROLE AND OBJECTIVES OF THE SOCIETY'S TRAINING DEPARTMENT

1. The Training Department is a staff service function reporting to the Controller of Personnel through the Training Manager.

2. The primary objective of the training department is to ensure that all staff are equipped with the skills required in order for them to help the Society meet its stated objectives. A secondary objective is to arrange limited aid and instruction for clients or potential clients as sanctioned by the Managing Director.

3. Training within the primary objective must be such that it aids the development of individual skills, thereby assisting in optimum career growth consistent with the Society's needs.

4. In order to accomplish these objectives:

4.1 It is the responsibility of Management to identify training needs, define the required skills, to assure the availability of personnel for training, and to finance all training costs.

4.2 It is the responsibility of the Training Department to aid Management in the definition, budgeting and planning process. It must arrange and make available the required training at reasonable cost, at the time required. The Training Department must minimize the time necessary for successful completion of the training.

4.3 The Training Department must ensure the continued effectiveness of all training it provides.

STAFF TRAINING PROGRAMME—1979

by R. S. Cornwell

INTRODUCTION

A decade has passed since a previous paper was presented outlining the Society's policies and proposals for training its technical staff. It is also approximately ten years (December 1970) since the Crawley training centre opened its doors to the first course. This would therefore seem to be an appropriate time to review present training policies and schemes within Lloyd's Register formulated to date.

When any training scheme is embarked upon there must be an objective and this was clearly stated in an earlier paper. Basically, the intention of the Society is to offer our clients a technical service of the highest standard and, through the years, training has become an integral part of maintaining this standard. Historically, technical training within the Society has been mainly given 'on the job' and supplemented by such external courses as the Kodak Industrial Radiography Course, the Control Engineering Course, held at the UK Firm of Automated Control Engineering and the Ultrasonic Course by Solus-Schall Ltd.

'On the job' technical training, under the direction of an experienced Surveyor, is probably the most valuable training obtainable, since actual experience is gained. However, there are disadvantages, for example, not all good engineers are good tutors, consequently there is not always a uniform standard of tuition. Secondly, owing to the many varied duties within the surveying disciplines, it is difficult to ensure that all objectives are adequately covered during the period of training without careful monitoring of the programme. Furthermore, in these days of contraction of the shipping industry, it becomes increasingly difficult to find any one outport which can afford all the practical training required to fulfil a comprehensive programme. Even in a port where the broader scope of surveying duties exists, recurrence of a certain type of survey is not always sufficient to provide the necessary experience in depth.

With respect to management training, the Surveyor was not previously offered formal training until such time as he was considered eligible for senior management positions. In the mid '60s the attitude of the Society towards training underwent a change as was intimated in the earlier paper and, with the opening of the Training Centres, at Crawley and Yokohama, a more formal approach was introduced,

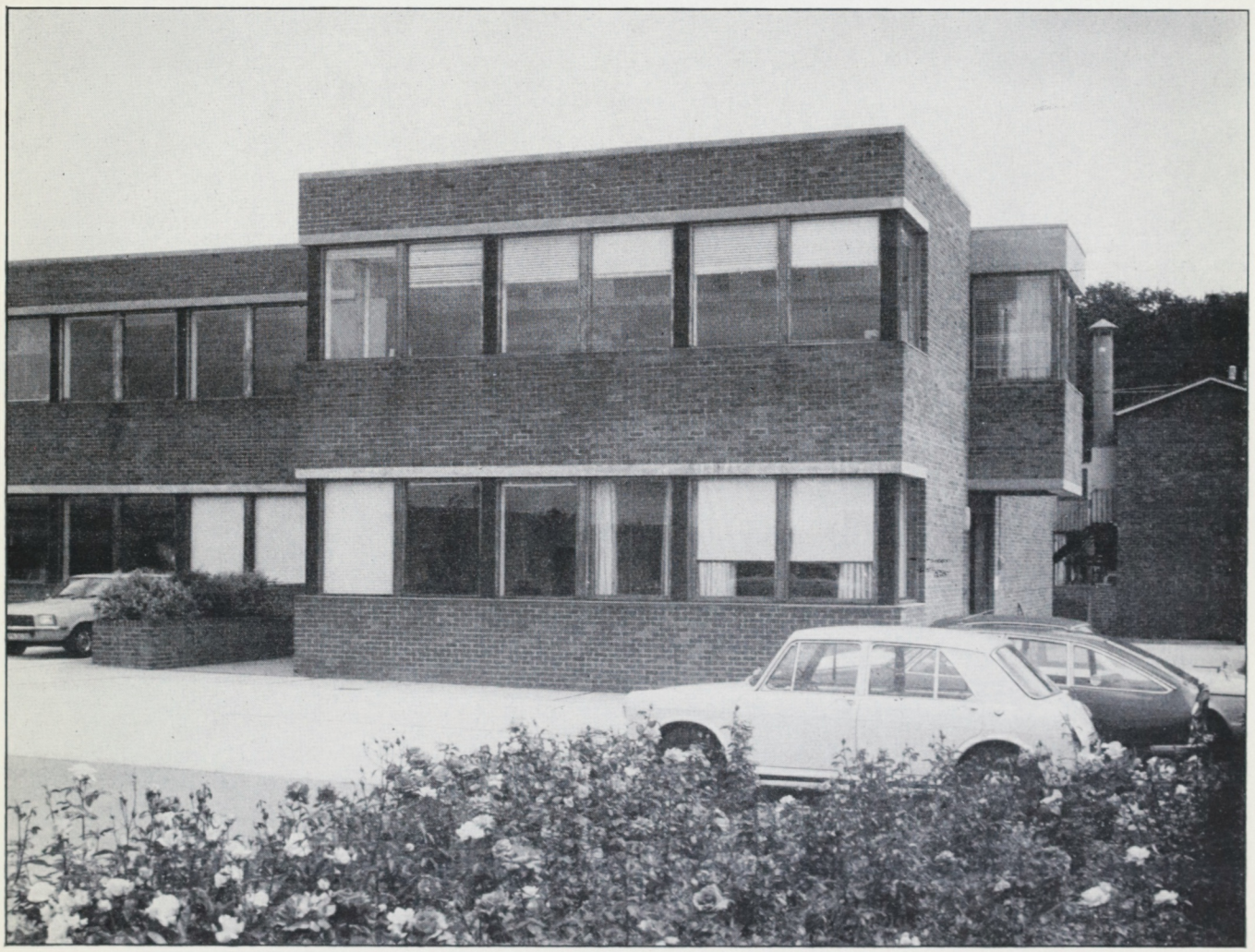

PLATE No. 1
Training Centre at Crawley

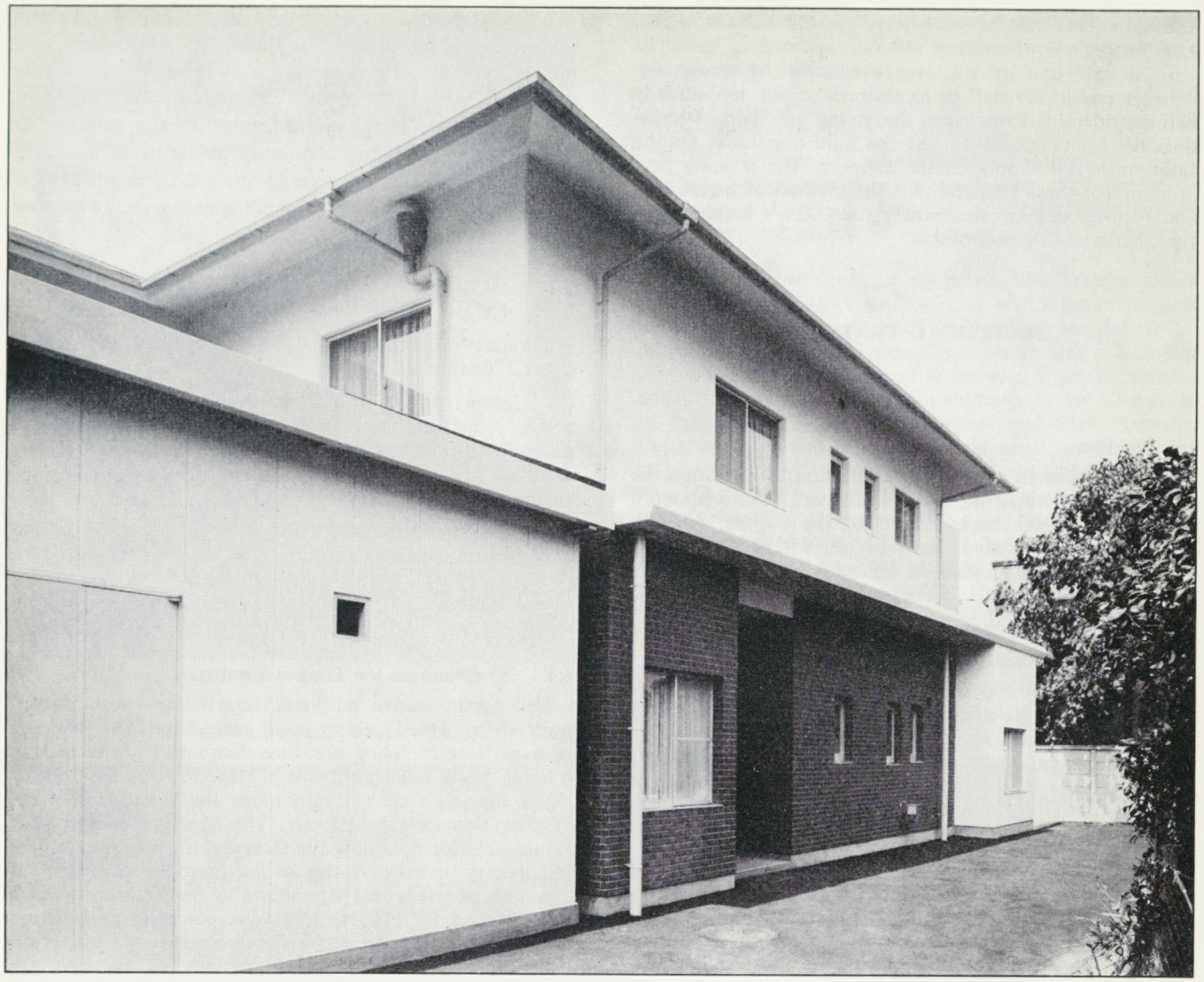

PLATE NO. 2

Training Centre at Yokohama

both in the technical and the management fields. A training manager was appointed and made responsible for providing a training service. His duties included certain administrative responsibilities for members of staff and clients on temporary duty for training purposes.

Today, the Society outlays a considerable sum of money on training programmes which include the technical training methods of long standing plus refresher and updating courses for qualified Surveyors. There are also induction programmes for Trainee and other newly joined qualified Surveyors. These can vary in length from between 1 to 2 weeks to some years. Also established at Crawley, and of increasing importance, are management and staff development courses.

No matter how experienced the technical staff are or how up to date they are kept, unless they are supported by an adequately qualified administrative staff the Society would not be in a position to efficiently supply the technical service required by its customers. In this competitive age. To remain viable, the whole of Lloyd's Register staff must work even more closely together as a team. Their working life must become more and more entwined and certain of the training needs must become more aligned, especially when considering management-related training. Therefore to present a properly balanced view, this paper makes mention of certain training schemes implemented and projected for all staff. It should also be noted that although training is the subject of this paper, career development will also be mentioned from time to time since training is an essential part of career development.

Until recent years, the Society's technical staffing needs were satisfied by recruiting experienced and qualified men. Owing to such factors as the shrinkage in world shipbuilding, and the emergence of new classification societies, this reservoir of manpower from within the marine industry is no longer large enough to maintain worldwide needs. To supplement the available skilled and experienced staff the Society has introduced a limited scheme whereby selected graduates, with little or no experience, are recruited as trainees. This method of recruitment, which was previously forecast, has probably caused the biggest change in the technical training policy within the Society in recent years in so far as basic training programmes have had to be devised to provide these young men with the knowledge

and experience needed to become qualified Surveyors to Lloyd's Register. Obviously, most of this training has to be 'on the job' and extend over a number of years, but, whereas previously staff being trained 'on the job' already had considerable experience, the young graduate of today does not know enough to 'ask the right questions', yet the tutor must still supply all the answers. The training programme for these trainees, plus the method of monitoring and recording, must also satisfy the C.E.I.'s requirements for Chartered Engineer Status.

TECHNICAL TRAINING

Introduction

The technical training schemes in current use within the Society are outlined in Table 1 and are described more fully later in this chapter. Parts of the training schemes have, as already stated, been in use within the Society over the years but mainly on an 'ad hoc' or 'as required' basis.

Reporting and Recording

To ensure that the staff are fully effective technically, not only should an efficient training programme be maintained but training records of individuals must also be kept up to date. These records must be readily available in the interests of the individual's career, and also as important added information for the Chiefs of Staff when looking for the right man for a particular niche!

A system of recording training completed and storing the information with other staff records in the computer has been introduced. It is the ultimate responsibility of the Training Manager, in discussion with the post-trainee's Manager, to ensure that all completed training commitments are recorded.

Where department or outport training has been undertaken, the reports submitted to the Training Department by the manager concerned should include fair and accurate assessments of the surveyor's capabilities, within the context of the training given. Included in the assessments should be details of any required training needs not completed. Trainees who have yet to attain Chartered Engineer status should also maintain a comprehensive record of their activities as is explained later in para 1.1.1.

1. INDUCTION AND INITIAL TRAINING

Training programmes under this heading can be considered broadly as:

(1) Comprehensive and basic training programmes for newly joined technical staff members, with insufficient general and practical experience, but who are academically qualified and who are normally recruited as trainee Surveyors.

(2) Limited programmes which are mainly procedural but may possibly include certain technical training elements, e.g. in cases where the newly joined Surveyor is not considered to be up to the overall standard required for full surveying duties.

1.1 Programmes for Trainee Surveyors

For administrative purposes, trainee Surveyors are appointed to Headquarters and placed on the training manager's staff. They are then temporarily attached to training ports or departments for specified periods during which time they are naturally under the jurisdiction of the Port or Department Manager. The Manager concerned is responsible for providing the technical training programme required in that department or port and for recording the Trainee's progress and capabilities in the Training Record Booklet (see Fig. 1). He is also responsible for ensuring that the Trainee mantains a comprehensive record of his technical activities. Liaison is maintained between the Training Manager and the Department/Port Managers,

TABLE 1

TECHNICAL TRAINING IN LLOYD'S REGISTER

Training Schemes	Technical Training Programmes	Supplementary Internal Technical Courses
Induction and Refresher training	Trainee Surveyors to follow the approved programmes	Metallurgical and Welding (M & W) Non-Destructive testing (NDT)
	Qualified Surveyors to follow programmes arranged locally	Basic Ship Course
Updating training	Informal, through:— Circulars; Technical Papers; Technical Associations, etc.	Ship; General Engineering; Yacht and Small Craft; NDT; M & W; Quality Assurance and Crude Oil Washing
Job Development	On the job training. Experience in areas in which the individual has limited previous knowledge	GRP, NDT, ASME, also Ship and/or General Engineering where Dual designation is being sought

Notes:

1. Surveyors may expect to complete from 3-5 years' service before being considered for updating courses in their own discipline.
2. A second updating course can be considered after approximately a further 8 years' service.

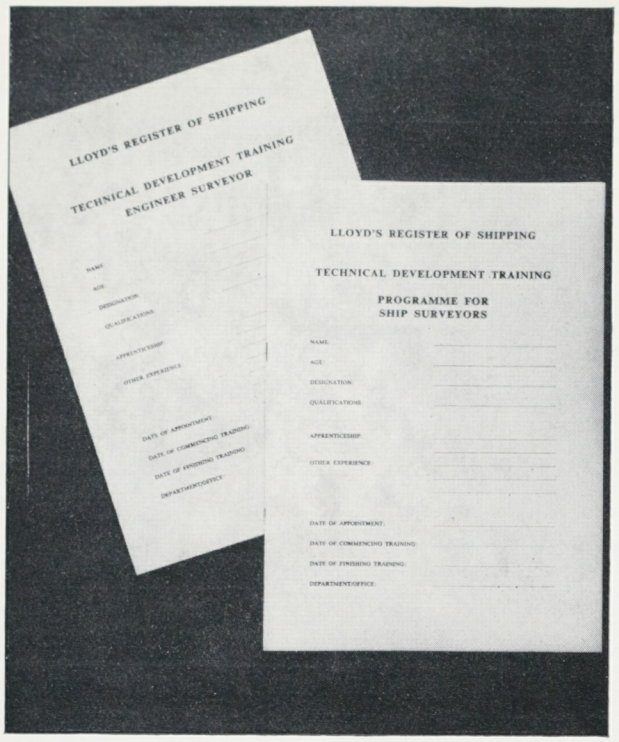

FIG. 1

Training booklets as used for recording a Trainee's progress

especially where exceptional situations arise in the Trainee's expected progress, e.g. in the case of illness, outstandingly good, or poor performance.

1.1.1 Trainee Engineer Surveyors

When recruiting trainee Engineer Surveyors, an apprenticeship and experience in an engineering environment are sought in addition to acceptable academic requirements. A marine background is not essential, but is obviously preferred.

During the first week of his service the Trainee spends four days at an outport and one day with a senior member of the Chief Engineer's Staff in Headquarters for an induction into his future duties. The main training programme is scheduled to span a period of between 2 years 2 months and 2 years 6 months. It consists basically of 12 months in the Machinery Design Appraisal and Plan Approval Department, where he is taught to apply his theoretical and engineering knowledge in the design aspect of machinery. He is given a grounding in the application of the rules for shafting, pressure vessels and pumping and piping, as well as offshore work. An introduction is given in the conversion of design calculations into computer programmes and the importance of stresses, alignment, torsional vibration and pumping and piping requirements. One year is spent at an outport gaining general experience in metallurgical processes, installation of new machinery, together with periodic surveys and repairs of machinery and boilers. Experience is also gained in drydocking procedures, including screw shafts, propellers, fastenings, sea

DEVELOPMENT TRAINING REQUIRED

PART I—PRACTICAL OUTPORT EXPERIENCE

TO BE COMPLETED BY THE HEAD OF DEPARTMENT AT WHICH DEVELOPMENT TRAINING IS UNDERTAKEN

SUBJECT		PORT/OFFICE	PERIOD	% OF TRAINING COMPLETED (WEEKS)	*COMPETENCY RATING A	B	C	D	E	MANAGERS INITIALS	COMMENTS (Recommendations for further training to be included)
STEEL TESTING	1. Plates and Section										
	2. Forgings										
	3. Castings										
WELDING	1. Pressure Vessels										
	2. Other weld fabrication										
N.D.T.	1. Welding										
Industrial Radiography Interpretation	2. Forgings										
	3. Castings										
	4. Pressure vessels, tubes and pipes										
Ultrasonic Flaw Detection	1. Welding										
	2. Plates										
	3. Forgings										
	4. Castings										
	5. Thickness Measurement										
Magnetic Flaw Detection											
Dye and Fluorescent Penetrant Inspection											
Eddy Current Testing											
MACHINERY CONSTRUCTION IN SHOPS	1. Steam Turbines										
	2. Heavy Oil										
	3. Gearing										
	4. Boilers										
	5. Auxiliaries										
INSTALLATION WORK INCLUDING PUMPING AND PIPING	1. Steam										
	2. Heavy Oil										

*COMPETENCY RATING: A = Exceptional, C = Average, E = Poor

FIG. 2

A sample page from the Training Record Booklet for Engineer Surveyors

DEVELOPMENT TRAINING REQUIRED PART I—H.Q. DEPARTMENTS				TO BE COMPLETED BY THE HEAD OF DEPARTMENT AT WHICH DEVELOPMENT TRAINING IS UNDERTAKEN							
DEPARTMENT	SUBJECT		PERIOD	% OF TRAINING COMPLETED	*COMPETENCY RATING					MANAGERS INITIALS	COMMENTS (Recommendations for further training to be included)
					A	B	C	D	E		
INTERNATIONAL CONVENTIONS—*(continued)*		2. Tonnage	17 days								
		3. Crew Accommodation	3 days								
		4. Damage Stability	5 days								
		5. Intact Stability and Grain Loading	15 days								
		6. Cargo Ship Safety Equipment	5 days								
		7. Lifeboats Lifecrafts and Davits	5 days								
		8. Fire Protection	25 days								
		9. Fire Protection of Offshore Installation	3 days								
		10. Codes for Chemical Carriers and Gas Carriers	2 days								
		11. Radio	½ day								
		12. Other Regulations	1 day								
REPORTS HULL	Principles and purpose of Classification										
	Classification Procedures including Outport office procedure Chapter 5										
	Visit to Classification Committee meeting										
	Instructions to Surveyors	1. New Ships									
		2. Existing Ships									
	Reporting Procedure	1. 1st Entry									
		2. Periodical Surveys									
		3. Damage Surveys									
		4. Towage Surveys									
		5. On/Off Hire Surveys, etc.									
SPECIFICATION SERVICES	Specifications	1. Writing Tenders									
		2. Appraisals									
		3. Plan Approval									

*COMPETENCY RATING: A = Exceptional, C = Average, E = Poor

FIG. 3

A sample page from the Training Record Booklet for Ship Surveyors

connections, etc. His final 2 months is spent in the Machinery Reports Department in Headquarters studying principles, purposes and procedures in classification, together with Instructions to Surveyors and reporting procedures.

Approximately one month before he is scheduled to finish his training programme he will be interviewed by either the Chief Engineer Surveyor or the Deputy Chief Engineer Surveyor. Provided his training record (Fig. 2) and the final interview are satisfactory the Trainee will be appointed to the basic Surveyor grade before continuing with any further training needs such as within Control Engineering, Refrigeration, etc. Within the terms of the trainee Engineer scheme these further subjects are classed as specialist training. In addition to the training, as described, a further period of fully recorded and certified experience will be required by the Technical Institutes in support of the individuals claim for Chartered Engineer status. This latter requirement is expected to be mandatory for all post-graduate new starters from 1st January 1980.

1.1.2 Trainee Ship Surveyors

The nature of some of the basic skills associated with certain of a Ship Surveyor's duties are such that trainee Ship Surveyors can be recruited without previous experience providing they have attained the qualifying academic standard. A flexible programme has been provided and is designed to provide a timetable of between 2 and 4 years with the length of training depending on the Trainee's previous experience. The programme consists of:

(a) a 2 week 'Basic Ship' Induction Course at the Crawley Training Centre. (see Appendix 1).

(b) 4-8 months in Hull Structures, with tuition in Structural Design, Materials, Longitudinal Strength, Hull Vibration, Welding, Propeller Ducts and some of the specialist aspects of Tankers, Gas Carriers, and Cargo Ships.

(c) 6-12 months in the International Conventions Department where studies will include the subjects of Load Line, Tonnage Measurement, Requirements for Crew Accommodation, Stability, Fire and Safety Equipment.

(d) 1-2 months introductory course into Offshore Work and 1-2 months in the Specification Services Department.

(e) 1-2 months in Ship Reports studying the principles, purposes and procedures in classification, also Instructions to Surveyors and reporting procedures. This period constitutes the final part of the training programme.

(f) The above Headquarters programme is supplemented by a comprehensive training programme in Outport surveying procedures and practices of between 9 and 18 months in length. Fig. 3 is an example page from the Training Record Booklet for Trainee Ship Surveyors.

Towards the end of his training the trainee Ship Surveyor will be interviewed by the Chief or Deputy Chief Ship Surveyor or one of their senior staff. Providing his record of training and the final interview are satisfactory, he will be appointed to the basic surveyor grade. As with trainee Engineer Surveyors it is expected that from 1980

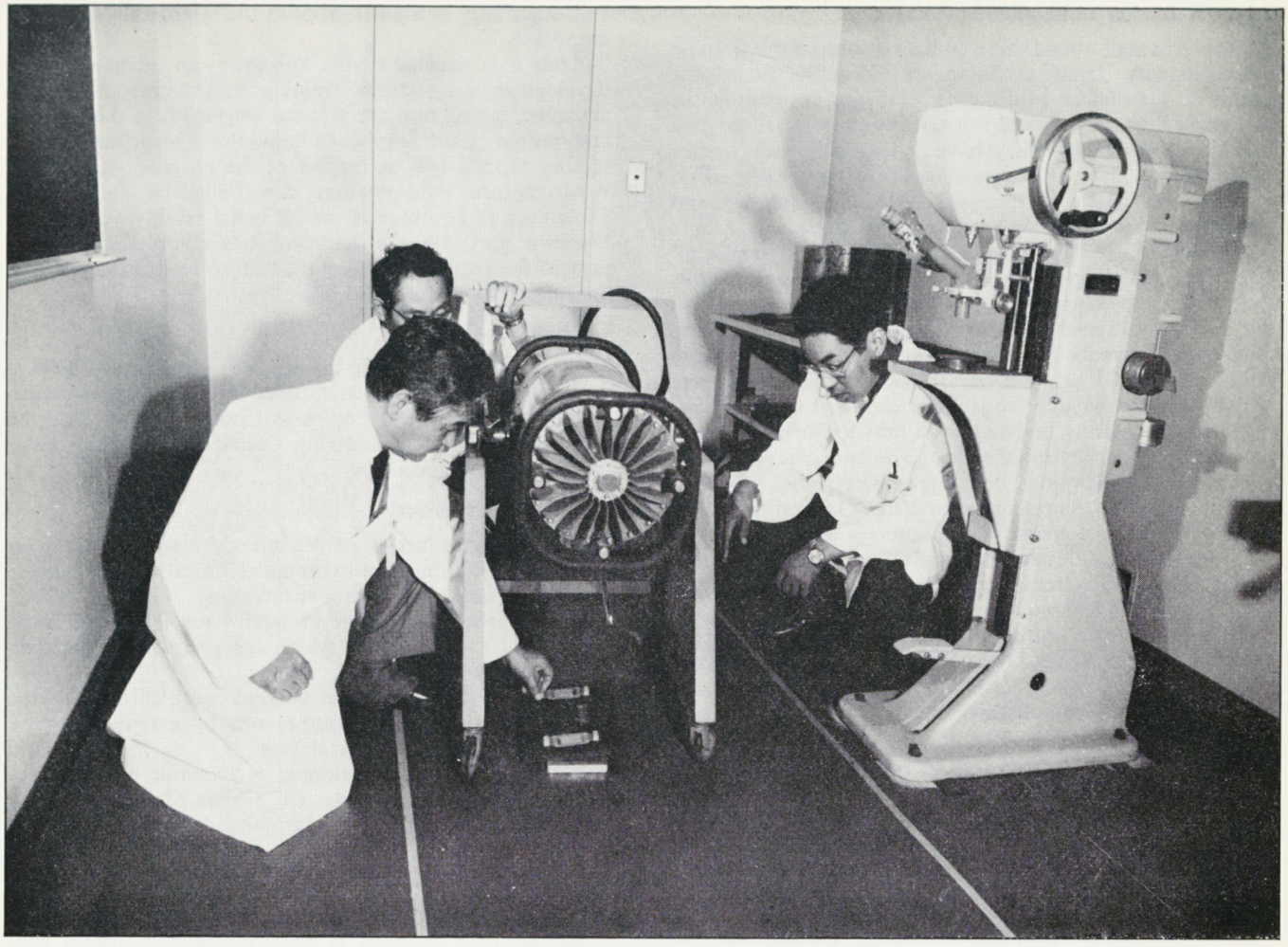

PLATE NO. 3

Instruction in Industrial Radiography at Yokohama

a further period of fully recorded and certified experience will be required to obtain Chartered Engineer status.

1.2 Induction Programmes for Newly Joined and Qualified Technical Staff

The content of these programmes is prepared under the supervision of the Department/Port Manager under whose jurisdiction the new appointee is placed. Any guidance from the Chiefs of Staff will be forwarded via the Training Manager.

1.3 Courses which Supplement Induction and Initial Training

1.3.1 'Basic' Ship

This course is held at the Crawley Training Centre for Surveying staff, within the 'Ship' discipline, who have had limited experience of survey duties. Trainee Surveyors will attend this course within their first few months service.

1.3.2 Metallurgical and Welding

Courses are held both in the Crawley and Yokohama Training Centres, the contents of the two courses being very similar. These courses are designed such that they can be used during the initial training of any newly joined technical staff member and also as an updating course for established Surveyors. The objective is to give all Surveyors the opportunity of attending this Course within his initial two years service.

1.3.3 Non-Destructive Testing

Courses are also held both in Crawley and Yokohama with the contents, again very similar at both centres. These too are designed so that they can be used as a refresher and updating exercise for established surveyors. In future they should be attended where possible within a Surveyor's initial two years service.

The contents of all courses are briefly described elsewhere in this paper but, in order to gain the best results from the Metallurgical and Welding Course and the NDT Course, as run at Crawley, it is recommended that they are taken in the order quoted above.

2. REFRESHER AND UPDATING TRAINING

This aspect of training cannot be too highly emphasised. One of the selling commodities of the Society is expertise. It is therefore essential that the expertise is maintained up to date.

There is a secondary point of view which sees refresher and updating training as a form of staff quality control, whilst there is another view which sees this form of training as a general confidence booster, especially where internal courses are concerned. Refresher and updating training, within the Society, is obtained via courses and through self study. Technical Association papers and meetings are recognised as an important part of the contribution to any updating procedures.

2.1 Refresher and Updating Courses

Technical staff attend these courses at one of the training establishments. Japanese Surveyors normally attend the centre at Yokohama whilst other staff are accommodated at Crawley. Surveyors will not usually be selected for the updating courses until they have at least 3-5 years service in the Society. These courses should not be considered on a 'once only' basis as they are, as stated, updating and refresher courses, which is a continuous process.

It would be ideal if all technical staff could retake all important updating courses at, say a maximum of five yearly intervals. However this is not practicable at present, but staff may expect to be considered for further updating courses at intervals of some eight to ten years after the initial course. To help obviate this apparent disadvantage to the updating scheme the training centre at Crawley despatches subsequently updated hand outs to Surveyors, who have attended a particular course. The two courses, which can be classed mainly as updating and refresher processes are known as the 'Ship Course' and the 'General Engineering Course'. The contents of the courses are described in Appendix 1. To a degree all technical courses can be used for updating and refresher purposes, but it is expected that the three-week NDT course which is currently held at the Crawley Training Centre will eventually be supplemented by a one-week course for the purpose. The one-week course will be only available to those Surveyors who have already attended a more comprehensive one.

3. TRAINING FOR JOB DEVELOPMENT

Occasionally management requires a Surveyor to further extend his present technical knowledge and experience to fit him for a particular post. A Surveyor may, alternatively take the initiative in extending his own capabilities. For example he might consider obtaining dual designation.

There are three main approaches to training for job development. The first and probably main approach is via 'On the Job' training, which can range from a few hours to a few months at a desk in headquarters, on field surveying duties at an outport, or a mixture of both. The second approach involves internal courses which usually supplement the 'On the Job' training and thirdly there are external courses available which can aid the Surveyor in his present job function.

3.1 Job Development

3.1.1 As a Management Requirement

Of necessity this training is arranged on an 'as required' basis. The itinerary is arranged by the Training Manager after consultation with the relevant Chief Surveyor or his Deputy, the Manager of the Port, and the Surveyor in question. The timing is arranged after consulting staff Department, the Manager of the Port in which the Surveyor is expected to be trained and the Surveyor. A report is required at the end of the training period from the Manager of the Port/Department and the Surveyor's personal file is annotated accordingly.

3.1.2 Surveyor's Initiative

Every effort should be made to aid a Surveyor who wishes to advance his job knowledge and experience within the framework of the Society's interests. If a Surveyor wishes to extend his responsibilities he can obtain advice from his Port/Department Manager as to the practicability of his plans. One prime example of job development is the technical achievement required in order to qualify for a dual designation. Appendix 3 outlines that knowledge and experience needed from both the 'Ship' and 'Engineer' disciplines.

After it is decided that a Surveyor can qualify for job development, a suitable training programme should be arranged, taking into account the exigencies of the Society, and centred on the Surveyor's home Port/Department. Satisfactory reports will be needed of the progress of the Surveyor before consideration can be given for further experience to be obtained which is not readily available in his own port. Once a Surveyor has completed a major part of the required training then more formal help can be considered to complete his objective.

4. Internal Courses

Courses which can help towards job development involve such subjects as Glass Reinforced Plastics, the American Society of Mechanical Engineers Codes, together with the Ship and General Engineering Courses where dual designation is being considered.

5. External Courses

With the introduction of the internal courses at Crawley and Yokohama the need to attend technical courses outside the Society has decreased for two reasons:

1. There is normally more in-depth knowledge, within the Society, of those subjects which are pertinent to the Surveyor's job.
2. Internal courses can be tailored more directly to the Surveyor's needs. Most courses run by external sources, contain material which is irrelevent.

Where it is felt that training is required which is not available within the Society, the Chiefs of Staff will give the necessary authority via the training department.

MANAGEMENT TRAINING

Introduction

Management Training is not a process of instant conversion of man to manager through a few hours of learning but a gradual development process. Neither should managerial effectiveness be measured by the number of hours of training, or the courses attended, but reflected in the contribution made by the individual to the performance of the Society. In the present competitive world, however, it is not satisfactory to reward a member of staff with promotion into a post, which is recognised today as being part of junior or mid management, without offering him or her some form of help. It has become increasingly recognised within the Society, that there is a need to give staff, at the various levels of management, tuition in the relevant principles.

The Society has for some years offered training in the management field for its senior staff and, once the range of technical courses was established in the training centres, attention was turned to improving and extending this training. Following a comprehensive review of management training in the mid '70s, part of which involved inviting a cross section of staff to give their views of training needs, a practical and logical sequence of courses were evolved for senior, mid and junior management.

To prevent confusion the term 'Management' was used in training to refer to senior staff of a level equal to, or above, Group Head or Country Manager status and so the term 'Management Training' has been retained for courses designed and suitable for such staff or for those who at the time of being selected are considered potential replacements. For the training of persons occupying or expected to occupy junior to mid management positions the term 'Staff Development' has been introduced.

A summary of the Development and Management Courses, both current and proposed, is shown in Table 2.

TABLE 2

MANAGEMENT TRAINING AS AN AID TO CAREER DEVELOPMENT

Course	Method of Selection	**Course Members Status		No. of Courses Per Year
		Technical	Non Technical	
Management	Course Members selected by Management Committee from nominations received via annual reports	Principals or above in grades A and B	Group and Department Heads	One
***Senior Staff Development**	Course Members selected by Chiefs of Staff from nominations received via annual reports and other recommendations	Senior Surveyors and Principal Surveyors Grades B–C_1 and C_2 and D	Department Heads and Deputy Department Heads	One/two
Staff Development	Course Members selected by Department/Country Managers, the Administration Manager and the Training Manager from nominations received via annual reports and other recommendations	Senior and Basic Grade Surveyors C_1 C_2 S_2 and D	Staff with supervisory responsibilities	Two/three
Junior Staff	Course Members selected by Administration Manager and the Training Manager from nominations received via annual reports and other recommendations	None	For Administrative staff with a minimum of two years service and who are considered to have potential	Two/three

*Still in proposal stage

**Where an actual grade is not quoted please refer to nearest equivalent

PLATE NO. 4

Audio Visual equipment being used in the training of the Society's staff.

These courses are at present only available at the Crawley Training Centre and, although obviously helpful to an individual in his career, are not intended in the foreseeable future to become a 'hurdle' to 'jump' before advancement.

1. Management Training for Senior Staff

Previously senior staff attended Management Training Colleges but, as with external technical courses, it was felt that for an organisation such as Lloyd's Register of Shipping there were certain limitations in the contents, inter alia, due to a lack of knowledge of the workings and operations of the Society by such tutors.

Once the Society's training centres were available, a leading firm of Management Consultants was invited to spend some time with the Society and, from the experience gained, asked to produce a course suitable for senior management. Initially the course content recommended was satisfactory but after a period of time, the consultant who had been attached to the Society was replaced and the advantages of consultancy were considerably reduced. To have kept the consultants up to date with the Society's requirements would have proved to be an on-going and costly business.

Considering the cost of bringing staff in from all parts of the world for courses, including the loss of potential earnings and the cost of relief staff etc., it was necessary to obtain as near to 100% useful tuition as possible from each course. The course instruction had also to be passed on, understood, and be of use to a multi-national group of participants who live and work in their own countries. For example, the legislation appertaining to health and safety in the UK would not be of particular significance to, say, the Society's staff in India, but the principles and reasons behind the legislation would be very much of interest for the well being of the Society's staff not only in India but in all theatres of the world. Certain UK legislation, such as with Health & Safety, is therefore included in the management and staff development courses but, where possible, only principles are discussed.

With an organisation such as Lloyd's Register it would be logical to assume that there is a wealth of managerial know-how and experience, as well as technical expertise, within its senior ranks and it seemed sensible, to tap this experience to provide the foundation of a management course. Executive and other senior staff were asked to draw on their individual experiences as the Society's managers and, by means of lectures and seminars, help provide a correctly balanced curriculum.

It would be wrong to say that instruction from outside the Society was not thought to be necessary. To rely solely on 'inside' experience, without the introduction of new ideas, methods and knowledge would obviously be a short sighted policy, as too much in-breeding would slowly polarise and blinker both thought and practice, which in turn would lead to the subsequent danger of stagnation. Outside expertise *is* needed, and used, in all spheres of instruction, but such tuition is mainly confined to basic principles.

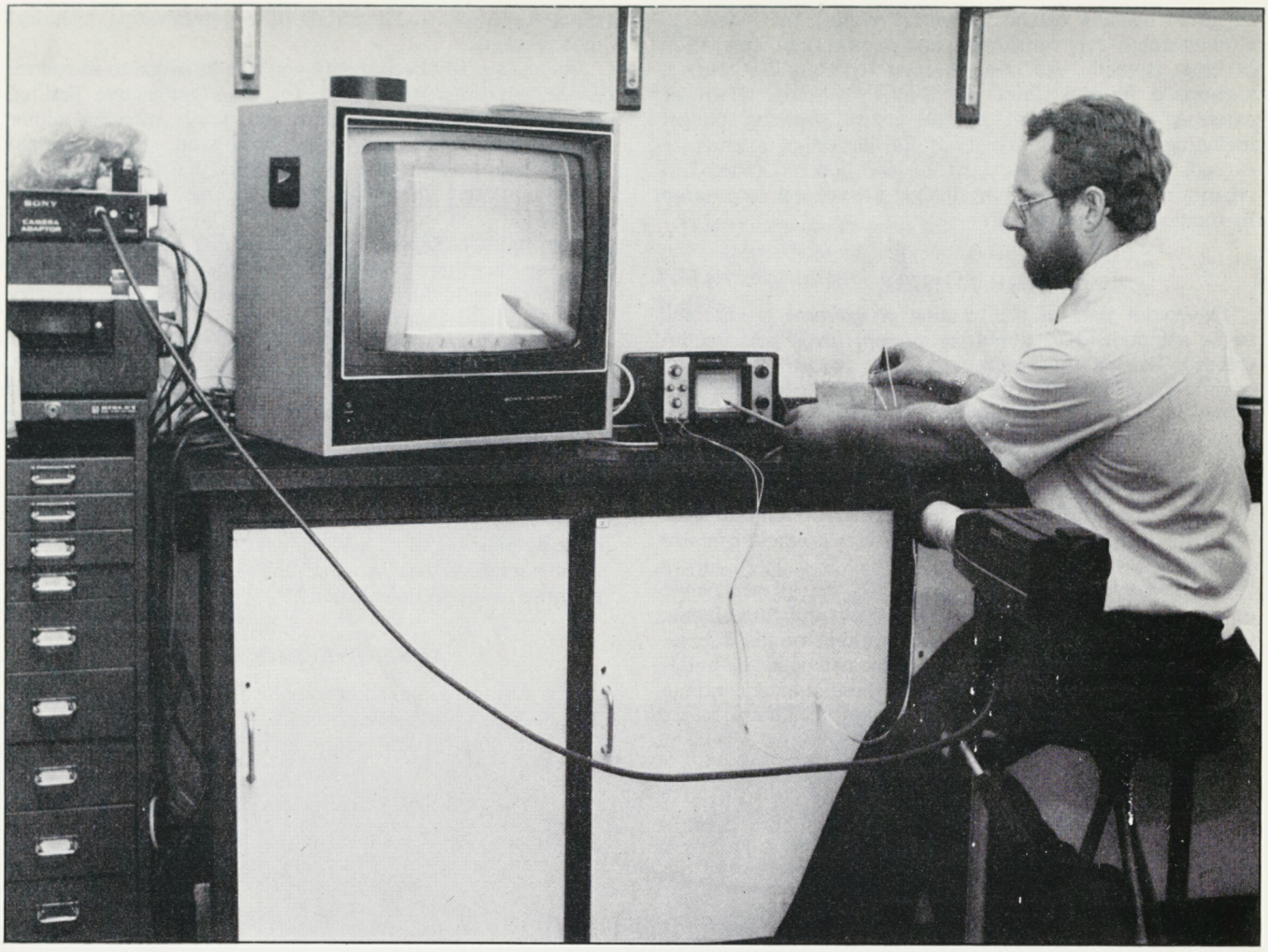

PLATE NO. 5

Closed Circuit Television being used to explain an ultrasonic trace to a large audience.

The management course produced from the above guide lines has been held annually at the Crawley Training Centre for the past three years and to date has been successful. A brief description of the contents and objectives are given in Appendix 2. Nominations received for this course are considered by the Management Committee who select the final list of participants.

2. Staff Development

One of the difficulties of producing a development course for all LR staff is the wide variety of disciplines involved. There can also be a significant age difference between staff holding similar supervisory and junior management responsibilities. This age gap can be accentuated because hitherto the Surveyor has not been recruited until fully experienced technically. He would then expect several years further experience before becoming part of the management team.

It was believed that Surveying staff needed guidance in developing management qualities during their early Society career, but it was considered that they would gain more advantage from tuition in such subjects as Finance, Organisation and Method, Communications and Customer Relationship. It was with these guidelines in mind that staff development courses, initially called Management I, were formed. By monitoring each course for its content via personal observations and suggestions and amending as necessary, a well balanced course has since emerged suitable for both technical and non technical staff.

The bulk of the tuition in this course has been left to consultants but Lloyd's Register speakers have been integrated at certain key periods to relate theory with the Society's practice. The objectives of the course are shown in Appendix 2.

3. Senior Staff Development

A further course in staff development is being planned and constructed for staff who are, or are expected to become, part of the middle management team, e.g. Senior Surveyors in charge of offices, certain Principal Surveyors, plus Administrative department heads, together with their Deputies. This Course, although giving some basic tuition in management aspects will, as in the Management Course, concentrate more on the Society's approach to management through seminars etc., especially in the subjects of New business, Finance and Staff control. The proposed programme is shown in Appendix 2.

COSTING

The first nine months service of a newly joined Surveyor is classed as induction training and his costs are charged against the central training budget. Where a programme

of initial training extends beyond this time the individual circumstances are considered and appropriate apposition of costs is made. All costs relating to attending courses, authorised by the Chiefs of Staff, whether internal or external, are chargeable to the central training budget including the cost of salaries if the period of attendance exceeds one month. As part of the control system all charges made to the training budget are subject to scrutiny by the training department.

THE FUTURE

The major part of the training programme is expected to be maintained at about its present level, perhaps increased. During the recent year new courses have been introduced to 'up date' the Society's surveying staff on such subjects as Crude Oil washing and Quality Assurance. Past experience indicates that there will be more subjects of importance emerging during the next decade coupled with the need for suitable new courses. Of great importance is the need to be ready with a fully updated technical staff when the Shipbuilding Industry recovers from its present depressed state.

From past favourable reactions to the present style of course presentation in both Crawley and Yokohama, which includes not just the formal content of the courses but the opportunity for impromptu discussions at the hotels in the evenings, it is necessary that these should continue in the same manner and provide the hub to the Society's training programme. Unfortunately however, only approximately 200 Surveyors can be given the opportunity each year of attending Crawley with a lesser number at Yokohama. Investigations are therefore continuing to find a practical and easy method of audio visual presentation which can be used, where considered necessary, to supplement the traditional methods of communicating technical information.

As has already been mentioned it is intended to introduce a one week refresher course for Non-Destructive Testing, for those Surveyors who have previously attended either the full course at Crawley or Yokohama or an external one. There is also a distinct possibility that further training will be needed in Control Engineering during the next decade.

The trainee Surveyor scheme which has been in option for over three years will need to be slightly reorganised to comply with the requirements of the CEI after January 1980 as previously explained.

CONCLUSION

The Society's training programme is based on the needs of its staff and is administered by the training department.

As the Training Department supplies a service it follows that the service provided can be no better than the *known* needs of the staff. The success, or failure, of the Society's training policy, and its development, during the next decade must therefore be, in part, the responsibility of every member of the technical staff.

ACKNOWLEDGEMENTS

The Author wishes to express his thanks and appreciation for the help and advice given by Messrs. E. Howey, R. G. Lockhart, F. H. Atkinson and R. F. Munro.

REFERENCES

1. Paper No. 1 Session 1969-70 'Technical Training and Information' by W. F. Stoot and T. Swiatecki.

APPENDIX I

INTERNAL TECHNICAL COURSES

The following is a synopsis of the contents of the technical courses offered within Lloyd's Register. Although they are shown in one, two or three week modules, at the Yokohama training centre the modules are occasionally split into smaller units to better satisfy local requirements.

Staff are selected for the training centre courses via one of two methods of nomination. Once a year Managers are circulated with the details of the Crawley programme of courses for the following year and nominations are requested. A section has also been introduced into the annual assessment forms to indicate training requirements. This section is in tear-off form which is forwarded to the Training Department on completion. It is included in the assessment form to allow discussion to take place at the annual appraisal interview around the individual's training needs. The final selection of the course members is the responsibility of the Chiefs of Staff, except that for the Management Course, participants are selected by the Management Committee.

Ship Course (Duration 2 weeks)

Week one

Mostly concerned with subjects and surveys dealt with by the International Conventions Department.
ICD subjects included are:

Stability
Grain Loading
Loadline
Tonnage Measurement (including Computer measurement)
Crew Accommodation
Fire Regulations
Passenger Ship Surveys
Safety Equipment
Radiotelegraphy Certification

Also included in week one are:

Quality Control, new ship construction.
IMCO & IACS, procedural details and information.
Corrosion Control, systems in use.

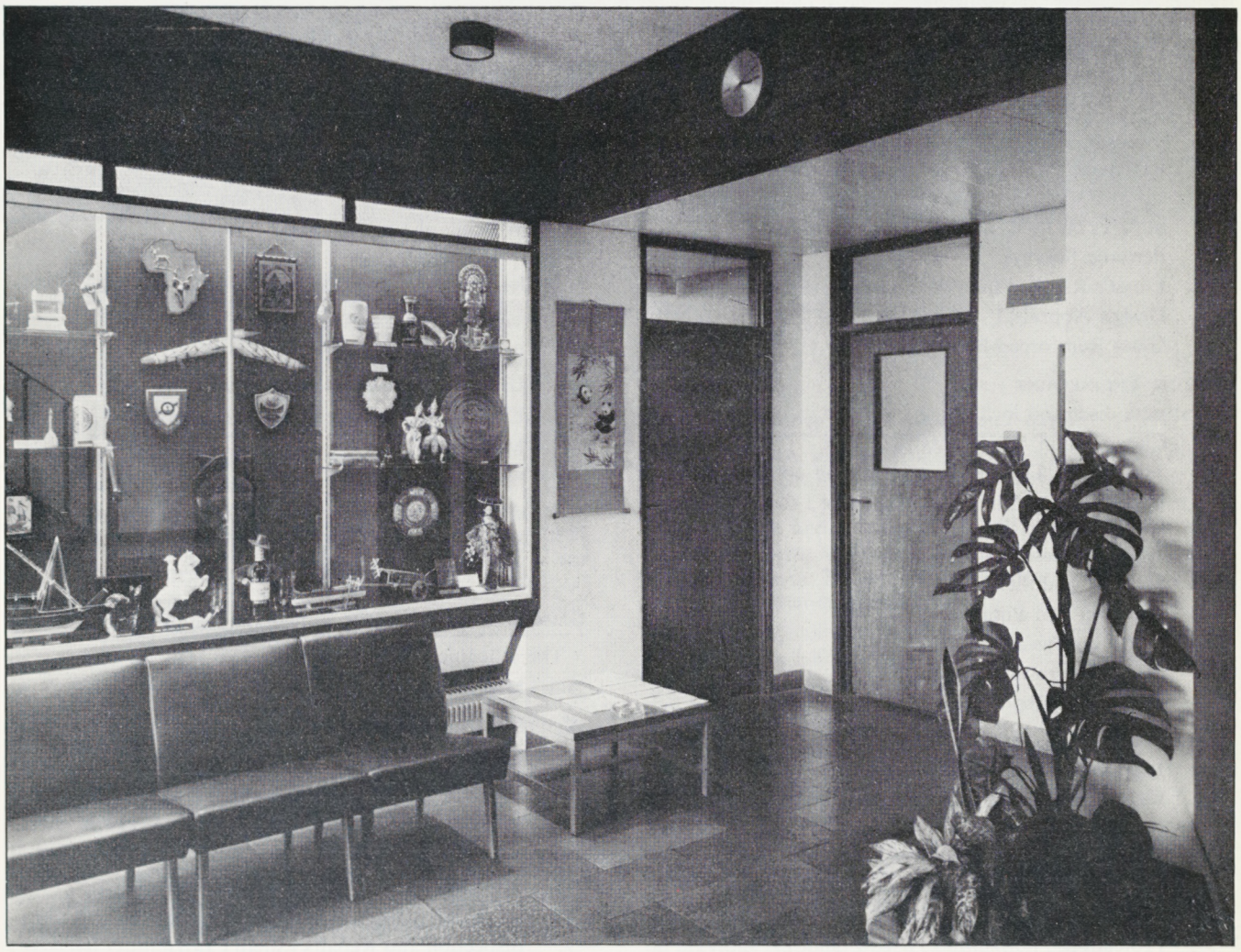

PLATE NO. 6

Within the hall of the Crawley Training Centre showing some of the gifts presented by staff world-wide.

Week Two

The emphasis is principally on the specialist fields dealt with by Hull Structures department.

Subjects included are:

1. Design, Construction, Repair & Failure symptoms in:
1.1 Tankers
1.2 Bulk Carriers and Container Ships
1.3 LPG, LNG
1.4 Chemical Carriers
1.5 Cargo Gear
2. Legal Cases—An insight into:
3. Damage Reports—London Salvage Association
4. On-Off Surveys etc.
5. Transfer of Class
6. New Business Intelligence
7. Specification Services
8. Ocean Engineering
9. Finance
10. Classification Procedures

General Engineering Course (Duration 3 weeks)

Week One

The first half of the week is concerned with the responsibilities and scope of Industrial Services Department with the main objective to give guidance in procedures. The remainder of the first week plus the remaining two weeks of the course is mainly concerned with marine engineering:

INDUSTRIAL SERVICES (details)

1. Guidance on Fee Quotation
2. Scopes of Survey
3. Containers
4. Surveys on Electrical Machinery
5. Periodic Surveys
6. Lloyd's Register Industrial Services (Insurance) Inc.
7. Design Appraisal
8. Glass Reinforced Plastics

MARINE ENGINEERING

Subjects discussed include:

9. Classification Procedures
10. Machinery Design Appraisal and Plan Approval including:
10.1 Crankshafts
10.2 Pressure Vessels and Boiler Design
10.3 Shafting and Stern Gear
10.4 Pumping and Piping
10.5 Inert Gas Systems
11. Boiler Survey and Repairs
12. Machinery Reporting

Week Two

1. Machinery Installation
2. IACS and IMCO: discussion and procedures
3. Bronze Propellers
4. Refrigeration including cryogenics
5. Electrical
5.1 Design
5.2 Protection
5.3 Surveys
5.4 Installations
6. Damage Surveys

Week Three

1. Introduction to NDT
2. Control Engineering
3. Vibration
4. Shafting Alignment and Torsional Vibration
5. Offshore Engineering
6. Quality Assurance
7. Internationl Conventions (Statutory Surveys etc.)
8. Technical Records
9. Finance

Metallurgy & Welding Technology Course (Duration 1 week)

The scheduled subjects include:

1. Microstructure and Heat Treatment of Steel and Cast Iron
2. Manufacture of Steel
3. Deoxidation and Degassing
4. Production of Ingots and Continuous Castings
5. Manufacture and Inspection of Steel Castings and Steel Forgings.
6. Steels for Pressure Vessels, Hull and Machinery Construction and for Low Temperature Applications
7. Welding Process Technology
8. Non-Ferrous Metals in Marine Applications
9. Welding of Aluminium Alloys in Marine Application
10. Welding of Carbon and Low Alloy Steels
11. Welding of Nickel Steels
12. Inspection and Quality of Welds
13. Welding of Stainless Steel

Non-Destructive Testing Course (Duration 3 weeks)

The scheduled subjects include:

1. Industrial Radiography
2. Ultrasonic Flaw Detection
3. Liquid Dye and Fluorescent Penetrants
4. Magnetic Flaw Detection
5. Eddy Currents

Included are discussions regarding the correct interpretations of the various codes, standards and practices in use.

Glass Reinforced Plastics Course (Duration 1 week)

The scheduled subjects include:

1. Materials
2. General GRP Fabrication Processes
3. Tools and Moulds
4. Approval of Materials
5. Storage and Works Conditions
6. Applications—Plant and Vessels
7. Testing—Inspection (Industrial Services)
8. Lifeboats
9. Inspection and Repairs (Small Craft)
10. Applications—Boats
11. GRP and Fire (restriction of use)
12. Faults found in GRP

PLATE NO. 7

Informal discussion group in session in the lounge of the Yokohama Training Centre

Yachts And Small Craft Course (Duration 1 week)

The scheduled subjects include:

1. Wood Construction
2. Materials
3. Wood Survey Procedures
4. GRP Construction and Materials
5. Engineering
6. Electrical Systems
7. Trials Procedures
8. Ferrocement and other Construction Methods
9. Services
10. Reports and Returns

Basic Ship Course (Duration 2 weeks)

This course has been designed for Ship Surveyors with limited experience of outport duties. The course consists mainly of practical lectures around the different types of surveys plus an appraisal of NDT methods and is followed by between six and eighteen months' practical experience at a selected Outport.

It is used as a technical induction course for Trainee Ship Surveyors and for career development of other staff as selected by the Chief Ship Surveyor or his Deputy.

Quality Assurance Course (Duration 3 days)

The purpose of the course is to acquaint Surveyors of the ways in which Quality Assurance techniques are being applied to Lloyd's Register Industrial Services work.

The theory and practice of 'total quality assurance' is discussed; as are the basic requirements for quality Management Systems. Reference is made to the requirements of British and other standards.

Note: The Quality Assurance Course held in Yokohama covers LR's total activity, i.e. in both the Marine and Industrial Services Field.

ASME Course (Duration 1 week)

The purpose of the course is to prepare Surveyors for the American National Board of Boiler and Pressure Vessel Inspectors examination in the subject of ASME Code Section 1.

Instruction is given by a consultant engineer from the United States of America. The course comprises a detailed study of the ASME Code Section 1, Power Boilers, and includes participation in working through questions based on previous National Board examination papers.

Selected participants proceed to America for a refresher Course prior to attempting the National Board examination.

APPENDIX II

INTERNAL MANAGEMENT AND STAFF DEVELOPMENT TRAINING COURSES

Management Course (Duration 2 weeks)

This course is designed to give greater detail and further advice in the principles of management, together with aid in effective speaking, costing and budgeting, customer relationship and methods of projecting the Society's image to clients and potential clients. This is coupled with an appreciable detail into all aspects of procedural matters, services and finance appertaining to Lloyd's Register.

The course objectives are:

1. To aid and provide information to Staff members who hold positions of relatively high responsibility in order to help them in the better execution of their duties.
2. To help prepare those members of staff who are expected in the future to be appointed to similar positions.
3. To provide a basis of aid and information to those staff members who may at some time in the future, be appointed to senior management posts.

Senior Staff Development (Duration 1 week)

This course is being designed for administrative staff approaching head of department level and will complete the current range of staff development and management courses available at the Crawley Training Centre. It will also be designed for senior technical staff who are, or may soon take charge of sections or units within the range of job grades B, C_1, S_1, and in certain cases, C_2.

The course objectives are:

1. To offer participants further study in the basic principles of management.
2. To give a deeper insight into the role of a manager compatible with the level of responsibility to be designated.
3. To give better understanding of the Society's policies associated with administrative and monetary functions.

Staff Development (Duration 1 week)

This course is intended to give guidance and instruction in such areas as leadership, motivation, staff appraisals and staff development, methods of communication and effective speaking, together with the compilation and writing of reports. It is recognised as a valuable aid to career development for both technical and non-technical staff.

The course is designed primarily for:

1. Surveying staff who are eligible or have recently moved to a position with some supervisory responsibility or where direct liaison or communication is required with clients or with other internal departments (e.g. those within Grades C_2, S_2, or D, as recognised within the UK).
2. Administrative staff and other non-technical staff whose responsibilities for supervisory and other junior management skills are minimal but may be expected to increase.

Junior Staff Course

The objective of the course is to give an up-to-date insight into the many roles and functions of the Society, together with an appreciation of the world-wide organisation. Guidance is also given in the various communicative aspects, as practised within Lloyd's Register.

In certain circumstances, technical staff in Grade E (UK Grading) will be considered (e.g. Trainee and Probationary Staff).

APPENDIX III

THE TRAINING REQUIRED TO REACH THE LEVEL OF COMPETENCE TO QUALIFY FOR DUAL DESIGNATION

Note:

It should be recognised that the technical content quoted within this appendix is fully outside my terms of reference and has been introduced on advice from, and with the approval of, the Chief Engineer Surveyor and the Chief Ship Surveyor.

1. INTRODUCTION

The requirements as set out in this appendix give a framework for guidance. It would be impossible to itemise all the expertise needed to satisfy the Chiefs of Staff that a candidate is suitable for Dual Designation.

For example, when surveying boilers, not only must the candidate have obtained a good knowledge of the working of and pressure parts of a boiler, a good understanding of the various types of safety valves and their adjustment, but also a detailed knowledge of the safety systems and controls (e.g. high and low level alarms, fuel shut-offs etc.). There is also a need for an awareness of the necessity to firmly secure and support valves and fittings, etc. also piping of both large and small diameter against vibration, (e.g. pressure gauge piping) with lubricating oil and fuel oil systems this is a principal cause of engine room fires. The candidate must also understand the need for good accessibility to important valves, to allow for rapid operation in the interests of speed and safety. With inert gas systems, he must understand why, for instance, a deck water-seal drain should not connect with a common drainage system.

Whatever the discipline, the candidate must be aware of the consequences of malpractice during any operating cycle, whether in service, under test or during cleaning.

Listed in this appendix therefore are the main subject areas in which satisfactory knowledge and expertise will need to be proven by report, demonstration, interview, past experience and/or written examination before approval will be given for Dual Designation.

The Training Department is available to assist in formulating any required programme. The actual content and length of the individual's programme will be influenced by previous experience and studies associated with the discipline.

APPENDIX IIIa

A GENERAL GUIDE TO THE REQUIREMENTS FOR A SHIP SURVEYOR TO QUALIFY FOR DUAL DESIGNATION

The candidate will need to satisfy the Chief and/or Deputy Chief Engineer Surveyor that he has a sound working knowledge and be reasonably proficient in the following areas:

1. A general knowledge of the main types of propulsion and auxiliary machinery as under:

1.1 A fairly intimate knowledge of shafting and bearings etc.

1.1.1 Types of Screw Shafts.

1.1.2 Stern bushes and their linings, e.g. white metal, lignum-vitae and tufnol.

1.1.3 Clearances, including the maximum permitted, in relation to diameter of shaft and type of lining of the stern bushes.

1.2 Types of Propeller, including:

1.2.1 Method and detail of fitting propellers to screw shafts.

1.2.2 Securing and sealing arrangements.

NOTE: All the above details must be fully understood as they are particularly vital for the safety of the ship.

2. A good knowledge of water tube boilers and scotch boilers including:

2.1 All working and pressure parts.

2.2 Safety valves.

2.2.1 The various types of safety valves available.

2.2.2 Methods of adjustment, with particular reference to the blow ring where fitted.

2.3 Safety Systems, including the water level gauge and its testing.

2.4 Controls.

3. Details of Cocks and Valves, including:

3.1 Identification of different valve types e.g. difference between (say) a screw-down non-return valve and an ordinary screw lift valve.

3.2 Correct locations and use.

3.3 Port openings and Markings.

3.4 Testing Procedures.

3.5 Adjustments (where applicable).

3.6 Accessibility.

4. A knowledge of high and low pressure oil systems (fuel, lubricating oil and hydraulic) and in particular:

4.1 Security of attachment of piping flanges and fittings.

4.2 Accessibility of valves for operation, including emergency.

5. A particularly good knowledge and understanding of the safety measures relative to pumping and piping in Oil Tankers; in particular:

5.1 The separation of systems, e.g. bunker and cargo oil.

5.2 Gas lines and relief valves.

5.3 Bilge drainage arrangements in cargo pump rooms

5.4 Cargo Tank Pressure Vacuum Valves.

5.4.1 Their operation.

5.4.2 Possible causes of failure.

6. An understanding of the safety measures required in an Inert Gas Installation relative to:

6.1 Oxygen content of inert gas.

6.2 Gas cleanliness.

6.3 Gas temperature.

6.4 Heavy corrosion and wastage to components and fittings.

6.5 The necessary inspection required for good maintenance.

7. A general knowledge and understanding of the electrical systems in use. Particular items are:

7.1 Insulation resistance (to earth and between cables) and the method of measurement.

7.2 Generator capacities relative to essential service ship load, including refrigerated cargo plant installation, where applicable.

7.3 The procedures to be adopted in the case of partial generator failure; e.g. where, say, only two generators out of three are working and the ship is required to proceed.

7.4 The function of the main swithboard circuit breakers, together with other protection devices.

7.5 Instrumentation; e.g. for synchronising alternating machines.

7.6 The supporting of cables, runs and glands, particularly where passing through bulkheads.

7.7 The types of fittings which are allowed in gas dangerous spaces, e.g. cargo pumprooms.

NOTE:

1. Where Surveyors of disciplines other than ship or engineer are seeking a dual designation and the second designation is either 'Ship' or 'Engineer' then the same criterion stands as shown before, e.g. an Electrical Surveyor seeking Electrical/Engineer designation would need to qualify in the same manner as a Ship Surveyor seeking a Ship/Engineer designation.

2. Where Surveyors are seeking a dual designation and the second designation is *other* than Ship or Engineer then each case would need to be considered on its merits and individual training programmes would need to be devised and approved by the Chiefs of Staff.

APPENDIX IIIb

A GENERAL GUIDANCE TO THE REQUIREMENTS FOR AN ENGINEER SURVEYOR TO QUALIFY FOR DUAL DESIGNATION

The candidate will need to satisfy the Chief and/or Deputy Chief Ship Surveyor that he has a sound working knowledge of ship construction, repair and maintenance as well as the application of statutory conventions. He should be reasonably proficient in the following:

Metallurgy

1. Manufacture and types of ship steel.
2. Various welding processes used in ship construction and repair.
3. Use of non-destructive testing techniques.

Experience in the following Classification Surveys

1. New construction for classification.
2. Annual Class Survey.
3. Special Survey.
4. Continuous Hull Surveys.
5. Docking Surveys.
6. Towage Surveys.
7. Damage Surveys (Temporary and Permanent Repairs).
8. Transfer of Class.

Experience in the following Statutory Surveys

1. Load Line.
2. Tonnage.
3. Crew Accommodation.
4. Cargo Ship Safety Equipment.
5. Radio/Radio Telegraphy.
6. Inclining Experiments.
7. Change of Flag.

Experience with Miscellaneous Surveys

1. Cargo Gear.
2. On/Off Hire Surveys.
3. Anchor and Chain Cables.
4. Quality Assurance.

The candidate is to be familiar with a variety of ship types and the constructional details associated with each.

He is to be aware of the expected areas of deterioration for each of the ship types in association with the cargoes previously carried.

The safety aspects concerned with entering into confined spaces is to be fully understood by him.

The candidate is to have a working knowledge of all surveys, reports and reporting procedures associated with ship discipline.

The correct use of journal and personal notebooks is to be demonstrated.

The surveyor is to demonstrate his awareness of the existing Instructions to Surveyors, Guidance Notes and other sources of information relevant to the ship surveyor.

He is to have attended the ship course as well as the NDT course.

Before applying for the dual designation it will be necessary for the candidate to have accompanied a Senior Ship Surveyor on most of the required surveys and to have demonstrated to him his ability to undertake the work unaccompanied so that the credibility of the Society is not impaired.

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Discussion

on

Mr. R. S. Cornwell's Paper

THE STAFF TRAINING PROGRAMME—1979

Paper No. 2 Session 1979-80

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The author of this paper retains the right of subsequent publication, subject to the sanction of the Committee of Lloyd's Register of Shipping. Any opinions expressed and statements made in this paper and in the subsequent discussions are those of the individuals.

Hon. Sec. S. M. Wehrle
71 Fenchurch Street, London, EC3M 4BS

Discussion on Mr. R. S. Cornwell's Paper

THE STAFF TRAINING PROGRAMME—1979

CONTRIBUTIONS

From Mr. F. H. Atkinson:

First of all I would like to compliment the Author on this very timely paper which illustrates the full range of training facilities available to the Society's staff.

This, as the Author states at the beginning of his paper, is the second such dissertation on this subject over the past ten years.

Before attending tonight's presentation I looked at the discussion which took place after Mr. Stoot's and Mr. Swiatecki's paper in 1969, which covered both training and information, and found during the discussion I suggested that all sources of information available within the Society should be periodically reviewed so that they may be updated or discarded as necessary, and therefore it is appropriate that this paper does exactly that with regard to training by Lloyd's Register.

Perhaps the first change one notices over the decade is that the Training Centre is considered no longer to be a technically orientated department and that all members of the Society have the opportunity to attend courses at Crawley, and indeed on a number of courses there is a mixture of technical and administrative staff and this cross fertilization is to be applauded.

It would be possible to comment on all of the courses mentioned by the Author but I will limit myself to perhaps the two most important, i.e. Initial Training and Management Training.

With regard to the programme for Trainee Surveyors, the Author mentioned the need for this to satisfy the requirements of the C.E.I. so that Chartered Engineer status may be obtained.

The introduction of young graduates into the Society at the age of 21 or 22 is a major but relatively recent change in the Society's recruitment methods. Having introduced Trainee Surveyors of this age it is essential that they obtain enough experience so that at the age of about 25 they are reasonably competent in all duties required of a basic grade Surveyor; but in parallel with this, they should also be fully acceptable to the C.E.I. as Chartered Engineers, and I would welcome the Author's views on how this will be accomplished.

Referring to Management Training, and in particular the two week course for very senior staff. I am concerned that no matter how well the attendees are chosen, no effort is made to assess their capabilities for future senior management within the Society. I would suggest, therefore, that each of the Management Representatives and outsiders who lecture at this course should make an individual assessment of each of the course members.

Having this done by a number of people, removes the subjective element and should provide a very useful yardstick for the future employment of the course member. Indeed I would suggest that this procedure be followed on all courses run by the Society. Again I would welcome the Author's views on this suggestion.

From Mr. L. Beckwith:

Having been involved with the Training Centre at Crawley since the first course on International Convention work was held there, I would like to congratulate the Author on, and make a few comments about, this very useful paper.

Although the few, who have been closely associated with training, will find little new in the paper, the vast majority will find, for the first time, a comprehensive list of available courses with associated comments.

This paper must be considered as a follow up to one, presented by Mr. Stoot and Mr. Swiatecki during the 1969-70 Session of the Association, which outlined plans that were in hand at that time. It is interesting to note that many of the things which were planned have come into effect and that some forecasts made in that paper have become realities. One thing mentioned at that time was the training of graduates straight from university. This method of recruitment which, as Mr. Cornwell has stated, is the biggest change in the Society's technical training policy in recent years must, in my opinion, be extended.

It is obviously in the early stages of development, and will inevitably require revision, but one aspect which does come to mind is the effect on busy H.Q. departments, and indeed outports, should the numbers increase. At present the small number of Trainees can be absorbed, but eventually it may be necessary to set up training groups within departments, or in ports, with the consequent need to detach one or more experienced Surveyors to supervise training.

There is one aspect of training not covered by the paper and that is the re-training of experienced Surveyors who are being transferred from one type of work to another. All too often the Surveyor asks for a day or two in I.C.D., and it is found that he is not aware, or has forgotten, all about requirements and procedures for statutory survey work. I have no doubt that the situation applies equally to other aspects of the Society's work.

While there may be records of training courses undertaken by individual Surveyors, are there adequate records of the types of experience they have gained during their years of service? It seems to me that such records are essential to guide those who decide on the suitability of a Surveyor for transfer, and that if the necessary experience is not available an opportunity should be given to the Surveyor to spend some weeks in H.Q. departments to bring him up-to-date.

The Author has mentioned the training centre in Yokohama. I am not clear, however, whether all the courses listed in the paper are available in Yokohama. Does the training centre there come under the control of the Training Manager and what area does it cover?

From Dr. D. Sepahy:

I would like to congratulate the Author on an interesting paper; however, he does not give any indication of the annual budget for staff training and I would like to know what this is, and also to see a statistical breakdown of staff in receipt of training. Is it possible to relate such statistics to staff turnover in the last five years?

The generalization made in the paper, that "the young graduate of today does not know enough to 'ask the right questions' " would not, I think, help to bridge the generation gap. I would like to suggest the other side of the coin with a similar generalization that graduates of yesterday do not grasp the problems of today. This raises the question of whether there are any technical training schemes for updating those in senior management.

I am surprised to read that senior management, i.e. Head of group or department, is not equipped to cope

with his work before his appointment and that he will be required to attend a management course *after* his appointment.

Senior management should attend seminars, conferences on management, economics, psychology, etc. and give papers themselves; not attend a 2-week course to cover material which should have been included at junior level.

Concerning technical staff on specialist grades (S2, S1), I would like to see more formal arrangements regarding their attendance at seminars and conferences, e.g. each specialist should attend at least one conference or seminar in a year on his specialist subject thus ensuring that he is kept up to date. At present this is carried out in a haphazard and inconsistent manner.

From Mr. A. E. D. Wilson:

I would like to thank the Author for his paper and would be interested to receive his comments on the following points.

Having experienced lecturing up to and including postgraduate level I found the quality of lecturing to be somewhat variable. In fact some of the most disappointing lectures were during my M.Sc. course, where some academics regarded lecturing as an unfortunate necessity between research papers. Accordingly, how is the quality of lecturing and presentation monitored?

Also, would the Author consider learning Foreign Languages as part of Staff Training? The rise in nationalism has surely reduced the number of foreign postings leading to fewer opportunities to learn other languages locally. The same influence also forces the Society to be more prepared to converse in other languages to retain its standing. Help with language tuition is surely of value to Surveyors requested to take on short term or temporary assignments or specialist visits.

Looking at the sample page from the Training Record for Engineer Surveyors (Fig. 2), I would be interested to know what proportion of the "Practical Outport Experience" described is considered necessary to complete training. The change in the Society's business must make it difficult to obtain training in all the aspects.

Since the Society requires all new surveying staff to achieve Chartered Engineer status, is the training geared to the requirements of a particular Institute? Would the Society have definite preference as to which Institute Staff should belong?

Finally, would the Author consider it desirable to allow visits to particular ships or installations by H.Q. specialists under a Training Budget? At the beginning of this year I was transferred to a specialist section after a certain amount of outport experience in one aspect of that department's activities.

To extend my interest to the remaining aspects will require some practical experience. With the necessity to charge for visits from H.Q. Clients clearly expect Surveyors to have gained the necessary experience.

From Mr. D. Prentice:

May I also congratulate the Author on producing this interesting paper. From my position as a newly appointed Trainee Ship Surveyor it appears to be very useful in outlining the development and scope of the training schemes, both during my training period and later in my career as a more experienced Surveyor.

I would like to ask a few questions pertaining specifically to my observations as a new Trainee, and in particular as one who has not had any previous, practical, shipyard experience.

Firstly then, I must point out one significant difference between the present Trainee Course and that undergone by past Trainees. Due to new C.E.I. requirements, a four year period will be required to attain Chartered Engineer status, and until recently the Training Course was about two years. I would like to ask whether the doubling of the time spent in each department is not excessive when it has apparently been adequate in the past. In particular I refer to the periods spent in H.Q. when I am really lacking in practical experience.

Secondly, I would ask why Trainees like myself, with little or no experience, have to wait a long time before being sent outside. I do not necessarily advocate initially being sent to an Outport for the full 18 months allotted, but perhaps for a couple of months of it. This, I would have found particularly useful, having spent $8\frac{1}{2}$ weeks in the Load Line Department without really having any practical acquaintance of the details of ship construction with which I have been concerned during this time.

Finally, I would suggest that it would be a good idea for a Trainee in the Load Line Department, for example, to be sent to London Outdoor to attend a Loadline Survey in order to consolidate his knowledge of the practical procedures involved, with the aspects considered at H.Q. because at the end of his training that will be part of the function of the Outside Surveyor.

WRITTEN CONTRIBUTIONS

From Mr. O. M. Clemmetsen:

Newcastle has always been considered a training port where a wide variety of experience may be obtained in both hull and engineering disciplines and therefore we have had frequent contact with the Training Department since its inception.

As stated by the Author, in the past newly appointed Surveyors were expected to have extensive practical experience before joining the Society, and in the case of ship Surveyors, the minimum age of entry was 27, while an age of 30 or more for engineers was common. With the advent of the Chartered Engineer and the necessity of having academic qualifications at degree level, the previous source of supply of men with practical experience has almost disappeared as far as hull Surveyors are concerned. In addition, students at Universities have great difficulty in obtaining practical experience before and during their courses. The result is that after graduation a further period of training is necessary before they are useful to an employer. Hence the scope of training has had to be expanded as shown in the paper.

Subject to the needs of the port, we in Newcastle have always tried to ensure that Surveyors attend some of the courses each year. When one considers that there are some 1800 Surveyors of whom only about 200 can attend courses each year, and that priority must be given to those who have travelled a long way from their home ports, it is not surprising that we have sometimes been disappointed in our training requests.

Out of the variety of courses provided, the one which has been most popular is that on Metallurgy & Welding which should be available to all field staff at some time in their careers, preferably as early as possible. This should be followed by the N.D.T. course which, however, has a disadvantage from the port's view point of being three weeks long.

The practical training which can be provided by a port obviously depends on the type and variety of work normally dealt with, and repair ports are at a great advantage in this respect. However, even in these ports certain types of survey occur infrequently, and attention must be given to the surveys actually under way on any one day in order that the Surveyor under training may participate at short notice. In this connection the Society is very indebted to the various Firms and Works visited by the Surveyors for their co-operation in permitting Trainee Surveyors on their premises, and the Surveyors whom they accompany should always make clear to Owners' Superintendents and others that such training does not involve them in any additional expense.

Referring to extracts from the Training Report shown in Figs. 2 and 3, it will be noted that, so far as Headquarters' Departments are concerned, specific periods have been alloted to certain subjects. Comparisons are perhaps invidious but it is noted that in I.C.D. fire protection is alloted 25 days, whereas the maximum period alloted to one subject in Hull Structures is 15 days for tankers and gas carriers. This does not seem to bear any relationship to the time which will actually be spent on these subjects in practice in the field.

In addition it has been noted that after the alloted periods in the departments the Surveyor is considered to have completed his training in that aspect i.e. 100% is given. It is concluded, however, that these percentages are only in relation to the training programme as a whole, since a period of 4-8 months in Hull Structures would hardly appear to qualify fully a Surveyor in that type of work. This leads to the comment that no specific periods are mentioned for any aspect of field work, and yet percentages are required to be inserted in the training report. Since field work, like hull plan approval, involves new problems with every ship, it is only after considerable practical experience that a Trainee Surveyor should be allowed to act independently. It might be noted that a Surveyor's academic training will have laid the ground work for many aspects of the work at Headquarters, yet for the reasons stated above, this does not now apply to field work. It would be prudent, therefore, for Surveyors who end their training in Headquarters' departments to again have an opportunity for further practical experience in the field accompanying an experienced Surveyor at the port to which they are transferred.

Referring to Appendices IIIa and IIIb giving the requirements for the two types of dual designation, at first glance it would appear that the requirements for a ship Surveyor to achieve dual designation are very much more onerous than for an engineer surveyor to qualify for dual designation. However, this is principally due to the fact that the specific hull items corresponding to those in Appendix IIIa are covered by the statement in IIIb that the "candidate is to be familiar with a variety of ship types and the constructional details associated with each".

It should be noted that the remarks under IIIb regarding reporting, use of journals and notebooks etc., will in practice also apply to IIIa.

In conclusion I would like to thank the Author for a most interesting paper.

From Mr. A. Jameson:

The Author has managed to up-date us all neatly and concisely, notwithstanding a little nostalgia for the older Surveyors, in recounting the history of training inside the Society. With an ever decreasing pool of outside sources from which to recruit, more and more reliance must be placed on training received after recruitment and even if traditional recruiting still existed, technology in the engineering discipline is advancing at such a rapid rate that internal training and up-dating are of major importance. It is interesting to look back to the early years when training was considered by most of the staff to be not only a fringe activity but a very doubtful one at that.

With regard to Appendix III—training for dual designation—it is suggested that from a practical viewpoint a formal record should be kept in the port concerned of each item or type of survey on which training has been given and on which it is considered the necessary expertise has been obtained so that the Surveyor concerned can undertake surveys on these specific items unaccompanied, although subject of course to the normal office supervision.

It is thought that a suitable standard format for record purposes and passing on to other ports could readily be devised.

Since training in the Society is overwhelmingly technically orientated it would seem logical that the Training Department should be directly responsible to the technical chiefs who not only control the content but also the personnel.

From Mr. J. J. Stansfield:

How does all this affect me?

This thought will be in the minds of many Surveyors when they read this paper. Although there is a wide range of training schemes and courses available to Surveyors, it

always seems to be the 'other person' who benefits from any training.

The validity of this is debatable, but there is one gap in the training scheme which ought to be filled. The Surveyor who has been in Head Office and is due for posting to an Outport is usually given an adequate training for field work, but if he returns to Head Office a few years later there is no corresponding technical refresher or up-dating course.

The 'cultural shock' of being posted to Head Office from outside especially from abroad takes a considerable time to overcome in itself, without the added burden of re-learning technical and mental skills.

For example, I found myself in the Ocean Engineering Department after a stint of eight years climbing around ships. Not only have I forgotten all but the basic theory of structures but also I am not familiar with the developments which have taken place in this particular field over the past eight years. Also the advances in computer technology and available software during this time leaves me mentally battered, baffled and bewildered.

Surely such drastic changes of job content warrant short refresher and up-dating courses, which would be of benefit to the Surveyor and to the Society?

It would benefit the Surveyor by increasing his confidence and by putting him on a more equal footing in relation to his less itinerant colleagues. It would also benefit the Society in that less time would be lost by the Surveyor and it would enable him to fulfill his new job function, and therefore his earning potential, at an earlier date.

From Mr. R. Guy:

The subject of Mr. Cornwell's paper is important reading matter to the young men undergoing training, and to older Surveyors who may wish to know the Society's strategy for the future.

A ten year presentation cycle is too long and it is suggested that the Author be requested to provide an appraisal of the situation existing in five years time.

The paper "Foreword" sets out the responsibilties of the Training Department and Management very clearly in paragraphs 2 and 4.1. In fact 4.1 is the all important paragraph because without adequate direction and finance the Training Department ceases to have a meaningful function in developing latent skills and providing basic knowledge in specialized subjects.

Following this foreword statement the actual financing appears to take a very vague form. We are told that training can extend from a short period to several years and in the latter category, when a newly joined Surveyor is involved, the first nine months are charged against the training budget. This is fine but the typical programme under 1.1.2 for Trainee Ship Surveyors provides for about 13 to 24 months attached to various H.Q. departments. It would appear that in the excess 4 to 15 months the Trainee is on the books as requiring a full return and one wonders at the attitude of the department head torn between the training vocation and hard finance.

Similarly, by the time the Trainee Surveyor attends an outport all central training back-up funds have dried up and the prospect of sending two fee earning Surveyors (one on a training mission) to any one job at a hard pressed port must provide difficulties for the Outport Manager.

The objectives of the training programme should include a realistic costing, beyond the first nine months, such that the individuals' needs are met rather than pressing port considerations.

Where a high volume of marine work was involved it was reasonable in the past to have separate marine/industrial disciplines in any office and the separation tended towards a rough form of efficiency. However, now that marine work is on the decline, surveying staff should be encouraged, and trained where necessary, to become proficient in all disciplines in order that we can remain reasonably efficient and attractive to industry; whether this be the marine, offshore or general industry.

From Mr. G. N. Snaith:

As a Trainee Engineer Surveyor, aptly covered under paragraph 1.1.1 of the Author's text, I would like to congratulate Mr. Cornwell on his informative paper on the whole structure of training within the Society.

In connection with attaining Chartered Engineer status, would the Author care to estimate the expected time between completion of training and becoming a Corporate Member of the Institute of Marine Engineers. Will this apply equally to the Institute of Mechanical Engineers whose constitutional regulations on post-graduate training have differed in the past.

Finally it would be interesting to know the ratio of past Trainee Engineer Surveyors absorbed into H.Q. to those who have proceeded to the various outports.

From The Port Staff of the Kanto Area, Japan:

Mr. Cornwell is to be congratulated on detailing so well the training facilities available to the Society's staff. This paper will be particularly appreciated by Surveyors in the field, who can so easily lose touch with changes in rules, regulations and modern concepts.

The Training Centre at Crawley is now fully operational and coping with many subjects which were not envisaged at its inception.

As the Society's interests expand into fields outside classification there will be an even greater demand upon it in the future.

In industry, management now places greater emphasis on staff being kept abreast of modern methods and systems. It is imperative that the Society must also ensure that its technical staff are capable of discussing and dealing with the advanced technological problems that they are likely to encounter.

It is felt that a closer relationship between the Society and the Ship Owners, in dealing with the manner in which statutory surveys are carried out, would be to their mutual benefit. Does the Author foresee the likelihood of Training Centres being established in other sectors of the world?

For some courses at Crawley, it was considered that more time should have been allowed. An examination of the contents of the courses, detailed in Appendix I, would confirm this opinion. The introduction of audio-visual presentation of the courses would help to overcome this problem if made available to the Surveyors in attendance. It is assumed that the audio-visual presentations will also be made available to the Surveyors who are unable to attend the courses held at Crawley.

Yokohama being a major new construction port, has experienced at first hand the decline in the shipping business, which fortunately in recent months has reversed.

The Author's comment on page 12, " Of great importance is the need to be ready with a fully updated technical staff when the Shipbuilding Industry recovers from its present depressed state", is considered to be of such importance that it should have been incorporated in the opening paragraph of the paper.

The content of the training programme has obviously been given much thought and covers the whole spectrum of our activities. It is considered, however, that the following particulars could be given greater emphasis.

Informal discussions are considered to be the most efficient means of communication and exchange of information, and it is felt that as a policy we should exploit this method more.

Where any port has four or more Surveyors, some time each month must be set aside for the purpose of discussion. The word informal is deliberately deleted, because to achieve the best results such discussion meetings must follow a defined pattern. At such meetings, problems encountered during the past month are formally tabled and analysed, any circulars, headquarters notices or Rule changes are explained and discussed, and finally the meeting is thrown open for Surveyors to discuss any subjects that are causing them concern.

We believe that such a system, variations of which are quite common in Japanese Industry and similar to a system taken up by Rolls Royce, would do much to reduce costly errors and enhance the Surveyors expertise, and has the important benefit of being low cost. Costs being limited to providing light refreshment if the meeting is convened for late evening.

Wherever possible, courses should be tailored with a definite objective in mind, e.g. N.D.T. courses must lead to eventual qualification and certification in accordance with the requirements of one of the recognized N.D.T. institutes. Training for Industrial Service Engineer Surveyors should lead to National Board examination standard.

It is not suggested that all I.S. Surveyors become A.S.M.E. inspectors, but that their training should be aimed at that level. As it is not possible for Surveyors to attend full-time courses for this purpose and in order to overcome this problem it is suggested that the training centre could extend its activities by organizing correspondence courses.

We are particularly interested in Yokohama to have more details of the A.S.M.E. Course. Would the Author please give more details including time estimates for completion of the full course, and percentage successful candidates.

Concerning dual designation it is suggested that there is, for example, with respect to ship and engine surveyors, two "degrees" in the dual designation programme. Where a Surveyor is fully qualified in both disciplines he will be designated "Ship & Engine" (F) or "Engine & Ship (F)", the major discipline of the Surveyor being first and the (F) denoting full proficiency as indicated in the appendices.

Where a Surveyor of, say, ship discipline has a reasonable knowledge of engine work, and is considered by the Port/Area Manager capable of undertaking general day to day engine duties, on either new or existing vessels, it is suggested he is designated as "Ship & Engine (P)", shipwork being his major discipline with a partial authority to undertake certain engine surveys. It is not envisaged that a Surveyor of this status would undertake boiler surveys, major engine damages or Salvage Association surveys.

Similarly an Engine Surveyor, with partial ship status, would be designated "Engine & Ship (P)".

It is possible that this may lead to a more efficient use of staff, particularly in ports covering large areas; and provide a better service to Clients, as in many cases one Surveyor's attendance will cover all works previously requiring two Surveyors.

Provided the limits of P designation Surveyors are clearly defined this system would be workable.

From Mr. M. Kurata (Yokohama):

Mr. Cornwell's paper briefly describes the Yokohama Training Centre which is the only establishment, outside the U.K., for the training of the Society's staff. I should like to expand a little on the Author's remarks.

The Yokohama Training Centre was opened in November, 1972 and reopened after complete rebuilding in July, 1978. On both occasions the official ceremony was carried out by the Chairman of the Japanese Committee.

When the Yokohama Training Centre was established it was decided as a matter of principle that the courses would be for the Japanese members of staff, given in Japanese by lecturers drawn from experienced members of the staff. The courses are based on the Crawley syllabi and in addition the lecturers have incoporated the fruits of their own experience into the lectures. This principle has been maintained with one exception, the Quality Assurance course, where the lectures are given by expatriate members of the staff in Japan who are specialists in the subject.

In addition to the staff lecturers, many specialists outside L.R. have been invited to appropriate courses as lecturers giving modern and detailed features in particular subjects, e.g. Quality Control of Pressure Vessels. L.P.G./L.N.G. Carriers, Defect in Steel, New Method of N.D.T. Assessment, Computerization in Quality Control of Shipbuilding, and so on.

The following courses have been given in Japan.

(Period from January, 1973 to December, 1979)

Course	Course Repeat and number of attendance
Ship	7 with 35 members
Quality Control in New Ship Construction	4 with 24 members
General Engineering	8 with 42 members
Industrial Service	7 with 36 members
Basic N.D.T.	10 with 57 members
Material & Welding	8 with 43 members
Control Engineering (External course)	3 with 13 members
Advance N.D.T.	2 with 11 members
Survey Report	3 with 14 members
Quality Assurance (The only course spoken in English)	4 with 19 members
	Total 294 members

The total attendance on these courses of 294 Surveyors means that on average every Japanese Surveyor has attended two, and sometimes three courses over this period.

In Japan, where the Shipbuilding Industry is still busy, intense competition between a number of Classification Societies call for quick and satisfactory response to our Clients. The training centre is seen to be of first importance in providing a wide range of up-to-date training. In this connection regular and close communication must be maintained with the Training Manager and Crawley Training Centre to ensure uniformity in the implementation of the Society's training programme. Advice on new courses, tuition, films, slides, course notes and recommended libraries and exchange of information is considered necessary.

Surveyors are often required to study from many reference books and established Rules, but many of them cannot afford to purchase expensive books. In order to maintain the Surveyors' technical standards, provision of ample

libraries is necessary and the Training Centre is being considered best as a centre for this purpose. Possibly a system of lending books to Surveyors in the Outports will be introduced for self study purposes in the near future.

The Administrative staff in Japan have also been invited to the Training Centre to study the Society's business operations. Recently, the concept and operation of the computerized business system has been included in the training programme.

The Yokohama Training Centre has also been receiving Trainees from developing countries in the Orient, whose training in Japan has been undertaken by the Society.

Co-ordination and planning of such training programmes has been carried out in the following cases:

For the Marine Inspectors of the Maritime Industries Authority, Philippines, totalling 20 Inspectors. Composing of 4 terms in a 19 weeks duration each in the period from 1975 to 1977.

For six persons of the Chief Engineers to PERTAMINA, Indonesia, for 7 weeks in 1977 in respect of ship control engineering.

2-Hull, 3-Machinery and 1-Electrical Surveyors to the Register of Shipping of the People's Republic of China who stayed in Japan for 7 months from February, 1979 to exercise the marine survey.

During the above mentioned training period, warm and positive co-operation from many Japanese shipbuilders and manufacturers was given, resulting in courses which were generally considered to be very successful.

From Mr. S. J. Van Haeften (for The Cape Town Surveyors):

Mr. Cornwell has produced an admirable paper which will be of great benefit to new entry technical staff and most certainly an asset to those of us already in the Society.

We are especially impressed with the manner in which the Author has carefully broken down the Training Programmes and Refresher/Updating Courses, and believe that the study of this paper is a valuable pre-requisite to all future course members, in that, one can now easily see in advance where certain knowledge may be derived to advantage.

In conclusion, we feel that the present rate of technological advance encountered by Surveyors in the field will make the Refresher/Updating Courses indicated by Mr. Cornwell, a tremendous asset to us all.

Additionally, with the increase of G.R.P./Yacht construction it is suggested that the Glass Reinforced Plastic Course (duration 1 week) and Yacht and Small Craft Course (duration 1 week) be conducted on a regular basis, and for Surveyors who are remote from the U.K., some form of correspondence course be arranged in the meantime.

From Mr. H. J. Tuttle (Vereeniging):

Mr. Cornwell is to be congratulated on writing a very interesting paper, however may I suggest that, in addition to recommending regular refresher courses, the course notes be alphabetically indexed to make future reference easier.

AUTHOR'S REPLY

Initially I would like to take this opportunity of thanking those colleagues who have contributed to the discussion.

To Mr. F. H. Atkinson:

Taking the case of a graduate Naval Architect with no previous experience, who is entering the Society as a Trainee, he can at present expect to attain Chartered Engineer Status within 5 years of starting his Training Programme. The Society's Graduate Training Schemes are at present being considered for approval by the appropriate technical institutes on behalf of the C.E.I. as being suitable training courses for graduates en-route towards Chartered Engineering status with the exception of the Institute of Mechanical Engineers who have accepted it already.

Referring to the question of assessing the capabilities of the delegates attending the Management Course for senior management posts, it would be to the Society's advantage if a satisfactory scheme could be established. It is the Author's view, however, that any assessment given would have only limited value. An assessment of a delegate given by a lecturer or panel member after only $1\frac{1}{2}$-3 hours acquaintance can only have limited credulance especially if it differs from the views of the delegate's own manager! If, however, such an assessment scheme were adopted, should the assessment stop at cease of work? Should not the delegate's behaviour be assessed during his off duty periods? A social-bore would not project the Society's image to any advantage.

To Mr. L. Beckwith:

The Chiefs of Staff are aware that before there can be any further extension to the Trainee Scheme, careful consideration will be needed as to the effect of the increased work load on those involved in the training. From discussions with Headquarter Department Managers, it is evident that a further increase of Trainees to the departments is unacceptable. The two main reasons are (a) the department's normal output would suffer and (b) there is insufficient seating accommodation available within the departments.

It was the intention of the author to show in the paper that the re-training requirements as described by Mr. Beckwith were dealt with under the general heading of "Job Development". This is an important area of training within the Society and further consideration will be given to extending it. See also the written contribution by Mr. J. J. Stansfield.

Whilst it can be confirmed that there are comprehensive records of training completed, Mr. Beckwith's query as to the recording of experience is outside the Author's terms of reference. However, it is confirmed that much work has been expended in amending the Surveyor's annual appraisal forms to include the recording of experience.

Referring to the question concerning the Yokohama Training Centre, the Author would reiterate that the Training Manager is the Society's Training Manager and as such has responsibilities to ensure that a satisfactory service is provided wherever needed.

The geographic location of the Yokohama Training Centre prevents close supervision by the Training Manager of the day-to-day activities but training records are maintained in Headquarters. Details of all courses held are also held in London.

Mr. Kurata's written contribution to this paper provides an excellent portrayal of the activities of the Yokohama Training Centre.

To Dr. D. Sepahy:

With an organization such as Lloyd's Register of Shipping, it would be difficult to show the full cost of training. Where does the costing begin? It could be argued, for instance, that the cost of providing relief Surveyors, to allow the release of resident Surveyors to attend courses, should be shown as training costs. There is also the disruption at the port from where the relief was obtained! Also the fluctuation of the pound makes it very difficult to implement a full training budget. By referring to the paragraph in the paper on 'Costing' (page 11), a general idea of the extent of the training costs can be obtained.

The cost of the training programme at Crawley in 1979 was in the region of £130,000. A breakdown of the number of Surveyors who have attended technical courses at Crawley to date are as follows:

	1979	Total
General Engineering Course	33	310
Ship Course	31	400
Non-Destructive Testing Courses	70	560
Metallurgy & Welding Course	69	318

The attendances at the Yokohama Training Centre is shown in Mr. Kurata's written contribution.

Where the Author wrote: "the young graduate of today does not know enough to 'ask the right questions' ", the Author simply meant that there is an obvious difference in level between the induction training needed for an experienced man (which is the only type of training many present day L.R. staff have experienced) and the approach which is needed when commencing the training of a graduate straight from university. This comment is meant to be no reflection on the young graduate Trainee whatsoever, as it is already becoming apparent that some will be more than holding their own in a few years' time.

Referring to Management training, it is the intention to give training before the appointment wherever possible—once a certain backlog is dealt with. Dr. Sepahy should, however, note the opening remarks of the Author under the heading "Management Training" (page 8).

Courses for Managers require to have a content applicable to the seniority and knowledge of the participant. They should also reflect the responsibility level that he is expecting to attain in the future. The contents of all the courses held at Crawley are in their present form largely as a result of criticisms and suggestions made by Surveyors who have attended in the past.

To Mr. A. E. D. Wilson:

Whereas some lecturers for an M.Sc. course may regard lecturing in the manner quoted by Mr. Wilson, the Society's lecturers are talking about their own specialist subject, and all attending Crawley courses, whether 'lecturer' or 'delegate' in the Author's experience are interested and enthusiastic in getting as much from the courses as possible. It should be remembered that part of the success of the Crawley scheme is the cross flow of information, not just from the lecturer to delegate, but from delegate to delegate *and* delegate to lecturer. The direct system of monitoring adopted with the Crawley Training Centre is in the use of Critique forms which the delegates are encouraged to complete.

Language training is part of staff training, but it is virtually pointless supplying a costly exercise until it is known the geographical location to which the staff member is being transferred. Unfortunately, by then there is not usually sufficient time available to complete a comprehensive training course. Linguaphone type instruction kits are made available on loan to all Surveyors on transfer or temporary assignment who need them. This may not be an altogether satisfactory arrangement, when bearing in mind the importance some nations place in the need for the resident Surveyor to speak the local language, but such training is under constant review.

It is not the intention to turn the Trainee into an expert in all aspects as shown in the Training Record (Outport) (after all, he is only available for between 9-18 months for outport training). It is hoped, however, to give him some knowledge "across the board" during that time. After his training is finished and he is appointed to his first post as a Surveyor, he will obviously need further training and experience before being competent, and even after that time, updating and refresher training throughout his career is necessary. It is the Society's hope, for their own careers' sake, as well as for the good of the Society, that all new Surveying staff attain Chartered Engineer status. The Society is very much aware that their training schemes must remain geared to this end. It is the individual's choice as to which Institute he wishes to belong. It is the Training Manager's and the relevant Chief of Staff's responsibility to ensure that the Society's training scheme is acceptable to the Institute.

If line management agreed that it was necessary for a staff member to make a visit as suggested, then it would be arranged under the training budget.

To Mr. D. Prentice:

The policy of appointing Trainees has only recently been introduced. The initial intention was to accept only those graduates who had some previous experience. Their training programme was approximately 2 years. Subsequently, the policy for Trainee Ship Surveyors was changed and graduates with little or no experience were considered, at the same time C.E.I. introduced a training plan, with a minimum of 4 years' duration, for graduates en-route to C.Eng. status. The Society's schemes were modified initially to take account of the lack of experience of the graduates and are now being further modified to comply with the C.E.I.'s requirements.

The Society recognizes that there are shortfalls and active consideration is being taken, which encompasses all the points made by Mr. Prentice, to improve the scheme. It is expected that amendments will be completed in the near future.

To Mr. O. M. Clemmetsen:

When considering the 1800 Surveyors as quoted by Mr. Clemmetsen, this includes all Surveyors who would not necessarily be required to attend courses through rank, age, disability, wrong discipline, length of service, etc. This does indicate that after nearly 10 years since the Training Centre opened, most of the eligible Surveyors have had the chance to attend Crawley at least once. The Author agrees that the two courses, Metallurgy & Welding and N.D.T. have proved the most popular courses at Crawley and steps have been taken to make more places available per annum.

Referring to Mr. Clemmetsen's remarks concerning the Training Report, as I have stated elsewhere, the Ship Trainee programme is being revised and in the light of experience gained, some parts of the programme will be amended.

Referring to paragraph 7, from discussions held it is understood that it would be difficult for the Outport Managers to measure the period of time a Trainee spends on a particular training aspect as usually more than one aspect is involved in any one survey. However, it was hoped that a fairly accurate estimate could be made of the Trainee's progress in the various aspects of field work which could be relayed in terms of percentage.

To Mr. A. Jameson:

As discussed in the paper it would be relatively simple to produce a formal recording document for training achievements en-route to dual designation and, who knows, with the present C.E.I. interest in the standard of training and level of qualification in respect of a person's primary technical discipline, how long will it be before correctly documented and substantiated evidence will be needed to support expertise in a secondary discipline.

In the Author's opinion, it is correct that the training operation should be located in that part of the organizational tree which has responsibilities to all staff. It is also just as important for the Society's Training Manager to be located at the right responsibility level within that tree as it is not uncommon for clients and recruits to judge the importance placed on an organization's training policy by that responsibility level. In Lloyd's Register, the two members of Senior Management with responsibilities to staff of all disciplines are the Managing Director and the Controller of Personnel and the Training Manager is responsible to the Controller of Personnel for "training in all its aspects, including the implementation of training policy in respect of the whole staff as directed by the Management Committee" (Quoted from his terms of reference).

To Mr. J. J. Stansfield:

It is suggested that although the Surveyor may be returning to a situation in which his skills are adequate but 'rusty' not only will he know this, but so will those in authority who have put him there. I would suggest that although he feels he is being "pushed in the deep end" management will allow him to take a period of time to re-habilitate himself fully into the post.

Field work covers a broad range of expertise and the Surveyor is expected to work on his own and make on-the-spot decisions during certain stages of the task. Headquarters work can be more in depth but there is help close to hand most of the time. Nevertheless the Author accepts the point being made and will discuss it further with the relevant Chiefs of Staff.

To Mr. R. Guy:

Referring to the financing of the Society's training programmes it is possible that the paper does not distinguish clearly enough between the position of newly appointed Trainee Surveyors and newly appointed Full Surveyors with respect to costing. Paragraph 1.1 explains under "Induction and Initial Training" that Trainees are appointed to the Training Managers staff for administrative purposes. The salaries, expenses and annual appraisals during their full training period are also the responsibility of the Training Manager, although in the latter area the views of the Senior Principal Surveyors under whose jurisdiction the Trainees have been during the previous year are sought before any entry is made to the appraisal form.

With personnel appointed as Full Surveyors their salary is a Headquarter cost for their initial 9 months service as explained in the paragraph on "costing" on page 11. Any appraisals which may become due are actioned by the line manager.

In paragraph 2 of his contribution, Mr. Guy asks for a 5 year programme. In the past it has been the policy to take note, and action where possible, of constructive comments from staff members, this will continue, and from the written contributions to the paper there have emerged some good ideas which need investigating. The Trainee Surveyor Scheme, for instance, if it proves successful in the field, can only grow and can quite possibly become the biggest growth area in training in the next five years. Now the courses have been proved it is hoped more technical staff will attend the Staff Development courses in the future. After all if the C.E.I. are requiring graduates to undertake management training during their training, the established staff should also participate or possibly stand the risk of falling behind in management techniques.

The Author obviously has no idea of any negotiations or other processes which might be in progress at Management level and which might result in further courses being formed. (e.g. the events which led to the introduction of such courses as A.S.M.E. and Crude Oil Washing).

One fact is certain the Society's training programme has been established to meet the Society's needs as they have arisen and there is no reason to suppose that the Society's needs will not be met in the future!

To Mr. G. N. Snaith:

As the Institute of Marine Engineers, the Institute of Mechanical Engineers and the Royal Institute of Naval Architects are all corporate members of the Council of Engineering Institutes and as the guidelines for graduate training programmes are given by the C.E.I., it is to be expected that the basics required from all the Institutes will be similar.

The C.E.I. base their requirements on a minimum of a 2 year training programme followed by a two year period in which experience is gained and responsibility attained. The training programme itself is divided roughly into 2 parts. One part is 'general' or 'core' training which is common to all training programmes, the second is more specialized towards the requirements of the employer. When such an approved programme has been completed satisfactorily, then the Trainee or Student is eligible for Chartered Engineer Status. It should be remembered though that although the newly appointed Chartered Engineer has attained a certain recognized standard, he is very limited in experience and because of it, he will take several years to reach his peak proficiency. When discussing graduate Trainees, this becomes a major problem with the Society, as experience is the mainstay of a good Surveyor. It is because of lack of experience that ex-Trainees can usually expect their first appointment to be in H.Q. or a large port.

It should also be remembered that 4 years 'in toto' is the minimum time acceptable by the C.E.I. and is associated with a completely satisfactory training programme. It may be that an employer cannot offer such a programme in which case, a compromise may be necessary, involving a longer training period.

To The Port Staff of the Kanto Area, Japan:

A small start has been made in the direction indicated by the contributors in their paragraph 3. During the Management course (the delegates which are, at the time of

the course, Senior Management or potential Senior Management), a discussion period is held to explore the interface between Client and Society. Guests attending the 1979 course for this particular discussion included:

Mr. P. Dixey	Past Chairman of Lloyd's Corporation.
Mr. J. J. Gawne	Chairman of Pacific Steam Navigation Co. and a director of Furness Withy and Co. Ltd.
Mr. G. A. Smith	Chairman & Chief Executive of Cammell Laird Shipbuilders Ltd.
Mr. R. H. A. Gezels	Senior Principal Surveyor for Belgium who attended in his role as E.E.C. Liaison Officer.

Replying to paragraph 4, once the courses were established at Crawley it was quickly realised that there were important "spin-offs". The most valuable of these, as has already been stated, was the get-together "after hours". It has been substantiated that these discussions play no little part in building confidence in the individuals. Even if suitable teams of lecturers were available at additional training centres, which they are not, this opportunity would be weakened.

Audio-Visual presentation is being considered, but finding a suitable system will undoubtedly entail more work on the already over-worked lecturer. However, progress is being made—but in the Author's view, whether audio-visual or any other assisted training is used at the home port the attendance at Crawley or Yokohama can not be superseded but only supplemented.

Due to the cost to the Society of supplying training worldwide the usefulness of such training must be maximised. One of the considerations taken into account when planning a course is outside qualifications, for instance the Crawley N.D.T. course is considered to be of a sufficient standard to qualify for A.S.N.T. level 3, except that a further extension to the period of training is required, which could, if necessary, be added at a later stage.

The first part of the A.S.M.E. Course is held at Crawley. The second part, refresher course and the examination are all held in the U.S.A. The main objective is to maintain a team of Surveyors qualified by National Board Examination in Boiler and Pressure Vessel inspection as per A.S.M.E. code section 1. Candidates are selected by management to attend.

Your suggestions concerning dual designation are interesting. However, as the Author states in his paper "although included it is outside his terms of reference". These proposals would need to be raised through a different channel.

To Mr. M. Kurata:

The written contribution by Mr. Kurata will do much to answer queries received, both verbal and written, which concern the Yokohama Training Centre and there is little further to add. It is believed, however, that the reopening in 1978 was carried out by the Chairman's wife.

There must be maintained a full and frank communication system between the two centres—in both directions.

Technical as well as Administrative staff should be allowed to study the Society's business operations; to a large extent, it is the Surveying staff who are expected to maintain and increase business. Possibly this study should be linked to some form of middle-management training similar to the staff development courses being held at Crawley.

To Mr. S. J. Van Haeften and The Cape Town Surveyors:

The Author will take up the question of the need for tuition in G.R.P. and Small Craft as an alternative to the annual courses held at Crawley.

To Mr. H. J. Tuttle (Vereeniging):

The updating of course notes is perhaps the biggest problem area of the Society's training scheme. This is not through any fault of the Surveying staff who lecture (who like the thought that there is in print dated material which is directly attributable to oneself). It is not the fault of the Training Centre staff who distribute and maintain the notes, it is—unfortunately for the training but fortunately for the Society's future—because the Surveyors who lecture are already fully employed in their own job—the preparation and updating of course notes are "extras".

The updating of course notes tends therefore to lag behind the traditional methods used to distribute technical information consequently their use for general reference purposes is NOT recommended without some form of cross check. The purpose of course notes is to give guidance to staff who are preparing to attend staff training courses. Abbreviated handouts, which can be more readily updated, are issued on the course. These handouts may need to be amplified in handwriting during the lectures.

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ON COMMUNICATING WITH COMPUTERS

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and
G. K. Henderson

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ON COMMUNICATING WITH COMPUTERS

by C. J. J. Beart, J. D. Short and G. K. Henderson

1. INTRODUCTION

1.1 From the start, the main advantage of computers over previous machines has been their versatility. Each new advance in computer technology has increased the range of tasks that can be undertaken with their help, and the pace of these advances has if anything increased in recent years. Yet even now it is sometimes difficult to achieve effective results from a computer in a reasonable time, as most of those who have used them will be aware.

1.2 There are several underlying reasons for this, some of which may not be apparent to the user who is not familiar with the details of computing. Among these barriers to effective use of a computer are:

the limitations of human beings in
- devising effective means to specify their requirements
- specifying their requirements
- foreseeing possible modes of failure
- storing and recalling large quantities of data reliably
- accuracy and consistency of action (e.g. due to fatigue)
- speed of communication and methods of communication (particularly in an outward direction)
- devising reliable mathematical models which avoid the pitfalls of approximation

and the limitations of computers in
- making effective use of past 'experience'
- interpreting imprecise commands or requests
- adaptability once programmed (they depend on human skill in forecasting requirements)
- methods of communication with human beings (particularly in an inward direction)
- rapid association of items embedded in large amounts of data
- reliability
- complexity of operation

1.3 Not only were these not appreciated in depth by the industry when computers were first introduced, but even now they have yet to be systematically categorised and studied. However, it will already be apparent from the above list that effective communication between man and machine, in particular from man to computer, is difficult to achieve. Not only is the effective bandwidth of communication low in this direction, but human beings have difficulty specifying their requirements precisely, while computers are poor at understanding imprecise statements. The technique of 'matching' circuit impedances to obtain maximum energy transfer will be familiar to electronic and acoustic engineers. Effective communication similarly requires the characteristics of source and destination to be matched, not only in bandwidth but in capacity and level of understanding.

1.4 The capacity of human beings for complete logical specification of their intentions is limited. Instead, having a long-term memory and an effective mechanism for association of ideas, they can often react correctly at short notice without reference to anything more than a rough statement of intent. On the other hand, computers, as they are constructed at present, are capable of following long sequences of instructions with guaranteed accuracy, but have little or no associative powers and therefore cannot react in a reasonable way to events which were not foreseen when the program was written. When preparing to use a computer it is therefore necessary to forecast correctly every eventuality which may occur during the execution of the program, not just to specify what is required.

1.5 Such eventualities may for instance result from:
- errors in specifying the procedure
- errors in the program
- errors in the data
- faults in the hardware (e.g. in a terminal or storage device)
- faults in the operating system or other basic software
- errors in operating instructions
- incorrect labelling or operation of archival storage
- insufficient storage or processing capacity
- external influences (e.g. failure of electrical supply or communication channel)

1.6 The amount of work necessary to achieve a given result with a computer can therefore be substantially greater than that required to solve the problem directly. In some cases this is a good argument for not using a computer; in many others the benefits, particularly in terms of speed and reliability, far outweigh the cost of the additional effort.

1.7 Of course, all of this additional effort should not be necessary every time a program is written. The effort expended in the last fifteen years by the suppliers of basic software (e.g. operating system programs, language compilers, packages for data storage and retrieval) has largely been aimed at reducing the user's need to concern himself with such matters, by providing proven tools for accomplishing common tasks and taking appropriate action when common faults arise. Unfortunately, each of these new tools has brought with it a new repertoire of commands, and the effect has too often been to increase the complexity of the computing activity rather than to ease the task of the user.

1.8 Over the same period, software costs have continued to rise, while the hardware costs have fallen. Thus there is now a much greater incentive than before for computer manufacturers to reduce the costs to the user of writing 'application software' i.e. of putting the computer to work. Fortunately, technology has enabled larger volumes of storage and greater processing power to be made available, and this has removed one of the main stumbling blocks to building more 'intelligence' into computers, that is the ability to take over more of the work involved in the man-computer dialogue. The software to exploit this capability to the full is still unfortunately some way in the future.

1.9 The dramatic reduction in the physical size of circuits and storage elements is also leading to an abrupt change in the man-machine relationship—whereas until now man has had to come to the machine, the machine has now begun to come to the man, in the shape of portable calculators, portable terminals, and shortly, portable bulk storage.

1.10 Furthermore, the cost of bulk storage of data on paper has risen substantially in recent years, and the cost of computer storage has already fallen to the point where it is beginning to look competitive with storage on paper (see Fig. 1). If this trend continues, as appears likely, effective methods of communication with computers will become a necessity for all of us.

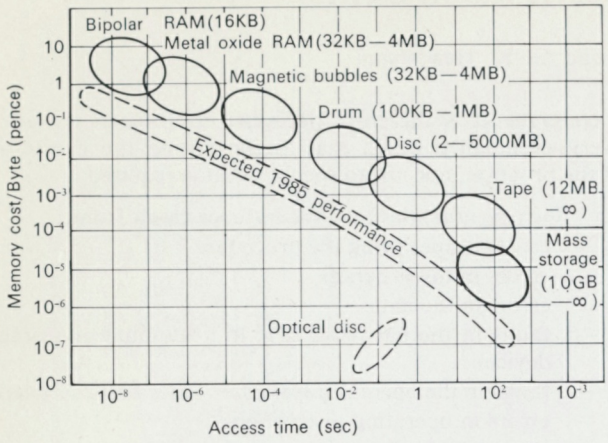


FIG. 1

Table of comparative costs of storage

1.11 It is therefore appropriate at this time to review the various aspects of communication with computers, and the developments which are now taking place in this field. Lloyd's Register has in recent years used computers for a wide range of tasks, and has been quick to make use of new techniques where these have been seen to be appropriate. Many of the techniques which will be in everyday use in the next decade can thus be illustrated by reference to applications or developments already taking place in this organisation. With this in mind the majority of examples are drawn from technical applications of computers within the Society, although many of the techniques will also be appropriate outside this field. It is our hope that this review will be helpful to existing and future users of computers within and outside Lloyd's Register, and in particular those who wish to use computers for engineering tasks.

2. MATCHING THE COMPUTER TO THE TASK

2.1 A pre-requisite for effective communication is clearly that the engineer uses the most appropriate type of computer for the job. The engineer requires different computing capabilities depending on the problem he has to solve. Whereas in the past he often had access to only one type of computer, the so-called 'mainframe' computer, there is now a bewildering variety of devices available, and more appear on the market every day.

2.2 To select the right computer for a given application demands a good understanding of the capabilities of each type of machine. Moreover to select the right spread of machines for future installation in an organisation demands not only a thorough understanding of the way the capabilities of such machines are evolving but also the ability to judge the effect these new capabilities will have on the applications themselves.

2.3 For example, the availability of suitable terminals and faster processors in the early 1970s allowed users to carry on a dialogue with computers for the first time, instead of being limited to communication over a scale of hours or days using punched cards or paper tape as an input medium. This in itself greatly enlarged the range of application of computers.

In the present decade, the advent of graphical communication from computers has already opened up many new fields of application. In the next five years further advances will certainly occur which will cause previously uneconomic applications to become economic in their turn. For example, array-processing techniques and cheaper storage will make computer simulation of the real time behaviour of structures and optimisation of design economically attractive for the first time.

2.4 Computers available today fall into the following categories:

Digital:

- Mainframe
- Mini (large mini-computers are nowadays called 'maxi' computers)
- Desk-Top
- Micro
- Word-processor
- 'Intelligent' terminal
- Calculator (hand-held, desk-top)
- Special-purpose (e.g. array processors, fast Fourier transform devices, associative storage devices)
- Computing networks (e.g. international networks)

Analogue:

- Electronic analogue computers (using operational amplifiers as integrators)
- Direct analogues (e.g. optical, mechanical)
- Spectral analysers

Device	Processor Speed (Millions of instructions per second)	Max I/O Rate (Bytes/sec)		
		To local peripherals ($\times 10^6$)	To local terminals/keyboards	To remote terminals
Calculators	0,0001	—	2	—
Word processor (Intelligent terminal)	0,001–0,03	0,1–0,5	10^{-1}	10–900 (limited by line speed)
Desk top computer	0,004–0,1	0,5–1	,,	,, ,,
Minicomputer	0,25	0,5–2	,,	,, ,,
Maxicomputer	0,35–0,9	1,0–8	,,	,, ,,
Mainframe computer	0,1–12	2,0–18	10^5	
Array processor	12–300	1,0–3	—	
Fastest projected computer	2000	?	?	

FIG. 2

Typical computer and communication speeds

Hybrid:
(incorporating analogue and digital components)
— Digital differential analysers
— Stochastic computers
— Analogue computers controlled by digital computers

2.5 Of these we are concerned here only with digital computers. All the above types of digital computer are already in use in Lloyd's Register. Each of them has particular characteristics which make it suitable for certain purposes and unsuitable for others. Typical characteristics of each type are tabulated in Fig. 2.

2.5.1 **Mainframe computers (Plate No. 1)**

These have the widest range of capability and are superior in processing performance and storage capacity to most other types. Sophisticated operating systems allow simultaneous use of the computer for a variety of purposes and by large numbers of users; alternatively the full power of the machine may be applied to one task at a time. Extensive on-line backing storage enables large quantities of data to be stored at low cost and accessed rapidly.

2.5.1.1 Applications involving high rates of input or output can be handled economically on these machines as the higher cost of fast input and output devices can be spread over many applications. Sophisticated devices of this kind do, however, need more protection, in the form of a controlled environment, than slower devices. Because of the wide variety of simultaneous demands on the computer, its work has to be carefully scheduled so on-line users may be subject to certain restrictions so that they do not adversely affect the service to other users. Because of the large software investment which can be justified by sales of such machines, the software available for them is extensive and they can be programmed in a large number of languages. However, due partly to this very versatility using one of these machines has in the past involved specialist expertise, and this can be a barrier to communication between the user and the machine.

2.5.1.2 More recently the power of these machines has been harnessed more effectively by devoting more of it to overcoming the problem of communication with the user. This enables more users to use the machine directly through terminals rather than through intermediaries, using less primitive computing 'languages' than in the past. One of the growing advantages of mainframes is also that their operating systems are increasingly incorporating measures for eliminating the security risks previously inherent in the use of a shared resource. As a result, the data stored in such a machine is safer and

PLATE NO. 1

The mainframe computer room at Lloyd's Register showing part of the IBM 370 installation.

less accessible to unauthorised users than if it were stored on paper, or cards or on a smaller machine.

2.5.1.3 The mainframe computer installed in Lloyd's Register is an IBM 370 Model 158 machine with 3 Megabytes of main storage, 3600 Megabytes of immediate-access disk storage, magnetic tapes and other peripheral equipment. Methods of communication with this computer now include:

- Card readers
- Line printers
- Graph plotters
- Remote Job Entry (RJE) terminals (for local or remote access through telephone lines). These are terminals with their own card readers, visual display units and printers, through which jobs may be submitted to the mainframe, and the results received and printed. Communication with the mainframe is in 'batch mode' that is, in bulk, rather than on an interactive basis, and jobs once submitted enter the normal batch job queues to await their turn for processing.
- Conversational Remote Job Entry (CRJE) terminals (local or remote). Similar to RJE, but data can be prepared, edited and stored using the power of the mainframe computer prior to submission. After the job has been run the output can be inspected in detail and further edited if required before printing.
- Interactive terminals (local or remote). These may be used to access the computer directly and to carry out computing tasks in 'conversational' fashion. Portable terminals are available which may, for example, be used 'on-site' during an engineering investigation or installed temporarily or permanently on customer sites. Interactive terminals of this kind may be used for much the same range of tasks as desk-top computers or word processors but allow the full power and storage capacity of a mainframe computer to be accessed as required. High speed communication channels (local only) permit very rapid transfer of data to and from local terminals (up to 800K characters/sec), but communication to external sites is limited by telephone speeds to 30-200 characters/sec depending on the terminal and line type.
- Facilities exist for connecting most types of computer, of any size, to the mainframe. In particular, this permits the connection of international computing networks to Lloyd's Register's mainframe computer, so that data may be prepared in other countries for submission to the computer and returned by the same means. Smaller special-purpose computers (e.g. for interactive graphics) may also be connected to the mainframe so that the characteristics of both can be used to best advantage. A further possibility is connection to the telex network.
- Magnetic tape. Data may be transmitted in bulk on magnetic tape to or from the computer. This medium is particularly suitable for bulk transfer of data in machine-readable form.
- Microfilm/Microfiche. Data may be converted to the form of microfilm or microfiche. This medium is useful for bulk reference data, where the number of enquiries per site is relatively low and communication costs are high but the data is not needed in machine-readable form.

2.5.1.4 Applications of the mainframe computer in Lloyd's Register are of many kinds, requiring substantial processing capacity, substantial storage, or a combination of both.

These include:

- Technical calculations, in particular large structural and thermal analyses, vibration studies, wave loading, stability and tonnage calculations.
- Information storage, maintenance and retrieval in such fields as Shipping Information Services, Technical Records, Staff Records, Classification and Accounts. All these functions involve the manipulation of very large data files and substantial quantities of input and output. Amongst this output is the copy for several substantial publications, including the Register Book.

2.5.2 **Microcomputers (and Maxicomputers) (see Plate No. 2)**

Minicomputers were originally developed for users who wished to construct their own software for one application in isolation, typically reduction or analysis of experimental data (a market area now covered by microcomputers). Subsequently they were developed and enlarged to the point where they were capable of many of the functions undertaken by mainframe computers. However, one feature contributing to the success of their low-cost design, the 16-bit word length, has until recently limited their speed and capacity. (Typical mainframes have a word length of 32 bits up to 60 bits, which enables larger areas of main storage to be addressed directly and greater arithmetic precision to be obtained in one machine cycle).

PLATE No. 2
PDP/11 Minicomputer

2.5.2.1 Recently 'maxi-computers', i.e. mini-computers with a greater word length, have been appearing on the market. These machines are comparable in speed to the mainframe computers of the mid-1970s and have a greatly improved storage capacity. The development of software for these machines has followed a similar path to that for mainframe machines, some five years in arrears. For some purposes this presents an advantage in that a moderate amount of raw processing power can be obtained from such a machine at a cheaper price than from a mainframe. However, there is evidence that as the versatility of the manufacturer's software for

these machines increases, the cost differential between them and the mainframe computers will disappear. Already a reaction is evident from the mainframe computer manufacturers in the shape of reduction in central processor cost. The distinction between the high powered minicomputer and the low- to mid-range mainframe is thus fast disappearing.

2.5.2.2 At the lower end, minicomputers offer somewhat lower capacity than mainframes at somewhat lower cost. They are thus suitable for special purpose tasks (e.g. data collection, invoicing, small time sharing tasks) with up to, say, 20 users sharing a common set of software, two or three running independent software, or one user requiring more powerful computing facilities than a desk-top computer can provide. Typical applications in Lloyd's Register of the latter variety include the creation and checking of data for the analysis of ship and offshore structures, logging, filtering, display and analysis of signals from measuring devices (e.g. on-line monitoring of sea states using a minicomputer and appropriate transducers mounted on board a ship, analysis of wave-buoy and strain gauge-data) and processing of images generated by a T.V. camera. Multi-user applications in Lloyd's Register include invoicing and data-gathering for accountng purposes. Minicomputers installed include two PDP-11/45s, a PDP-11/34 and a Ventek 5500 computer.

2.5.2.3 Due to their smaller size and lower performance than mainframes, minicomputers require less environmental control and are easier to site. The amount of specialist knowledge required to operate and develop software for these machines is often greater than for mainframes as more software for minis tends to be 'home-grown'. Thus measure for measure, software support cost for minis is greater than for mainframes, where support costs can be spread over a larger number of users.

2.5.2.4 An even wider variety of terminals may be connected to minicomputers than to mainframes. Minis are thus often used as hosts for experimental configurations involving new terminal devices.
Terminal devices connected to minicomputers at Lloyd's Register include:

- 3-D refresh-graphics displays (Vector General 3D3)
- Storage-tube graphics displays (Tektronix)
- Alphanumeric visual display units (characters only)
- Typewriter terminals
- Analogue to digital converters (for reduction of experimental data)
- Fast Fourier transform devices
- Image scanners (T.V. camera)
- Computer-computer links to mainframe

2.5.2.5 The range of manufacturer-supported programming languages available on a minicomputer is more limited than on a mainframe but a large variety of experimental software is often available from other users.

2.5.3 Desk-top Computers (see Plate No. 3)

These have been developed from desk calculators and, as the result of recent advances in LSI (Large-scale Integration) circuitry, have now acquired some of the characteristics of larger computers. In addition they offer the advantage of small size and convenience in use.

2.5.3.1 The most recent type of desk-top computer to be used extensively at Lloyd's Register is the Hewlett-Packard 9845. In addition to a processor of considerable power this incorporates a raster-scan* display with resolution approximately 500×500 picture points. This machine is considered to mark the transition between the 1970s and the 1980s in terms of ease of use and compactness. Because of its powerful graphical display capabilities it is particularly suitable for engineering applications. Interfacing of these machines to more powerful computers with greater storage capacity will progressively give the user the best of both worlds in the fairly near future.

PLATE No. 3

An HP 9845 desk-top computer

2.5.3.2 Principal characteristics of desk-top computers are:

- Speed and main storage comparable with smaller mini-computers
- Limited backing storage, usually slow speed (but additional backing storage can often be attached, at additional cost)
- Single user
- Usually single language (normally BASIC or APL)
- No special environment needed—mains power supply
- No support staff required
- Simple to use

2.5.3.3 At Lloyd's Register desk-top computers are used increasingly both at HQ and at the outports for the relatively small scale calculations associated with routine plan approval, using software developed as part of the LR PASS system. In addition software for direct design calculations has been developed and is offered to clients for use on their desk-top machines. Other areas of application in Lloyd's Register include machinery design and plan approval, offshore structures and International Conventions work.

*See paragraph 4.5.4.1

2.5.3.4 There are many reasons for the popularity of desk-top machines, not the least of which is the apparently ready availability which they offer the engineer. The irony is of course that this popularity quickly reduces their availability, requiring the purchase of more and more machines. Although astonishingly cheap compared with their 1960's (and early 1970's) counterparts, they are still a factor of ten more expensive than terminals attached to a mini or mainframe computer.

2.5.3.5 During a typical hour-long session at a desk-top computer or terminal, the machine is probably usefully active for about 5 minutes. The other 55 minutes is user thinking time. In any situation there is thus a continuing case for using cheaper terminals if a larger computer is available, particularly if access to larger volumes of storage is required. On the other hand in countries where access to a larger computer is difficult these machines offer an excellent tool both to outport and the smaller shipbuilder.

2.5.4 **Microcomputers**

These machines embody the most recent developments in silicon chip technology, enabling very powerful processing facilities to be built into physically very small units. They are now beginning to be used in a very wide variety of fields, indeed all those fields in which logical decisions have to be made, for example, automatic controls in every industry from automobiles to washing machines, monitoring and inspection devices, and business equipment. Perhaps their best known role however is as the active component of pocket calculators. Increasingly, too, they are used as components of larger computers, from desk-top calculators to mainframes, and in that role have contributed largely to the reduction in size and price of such machines. They are particularly well suited to environments where small physical size or power consumption is important, e.g. in portable devices.

2.5.4.1 In all these fields, however, they need to be interfaced electrically to input, output and storage devices, packaged in a convenient manner and provided with software. The average user of computers who lacks the necessary facilities and knowledge of electronic engineering is unlikely to use these devices directly. Instead he will meet them in the guise of one of the other types of computer outlined here, or as part of an industrial component or business machine, and may well not even be aware that a microcomputer is involved.

2.5.4.2 While the cost of microcomputers is low, by the time they have been suitably interfaced, packaged and provided with input and output devices and software, the cost of the resulting machine is usually of the same order as desk-top computers or word processors or greater if software is developed for a one-off application. The only way in which the cost of the software can be brought down to the same order of magnitude as the machines themselves is to apply it to a mass market, as in automobiles, washing machines, calculators and the like.

2.5.4.3 The inverse relationship between cost on the one hand and the reliability and life of input and output devices must also be considered; a computer, however cheap, is of little use if the devices through which one communicates with it are unreliable.

2.5.4.4 Large numbers of microprocessors are already at work in Lloyd's Register. Almost all of these are of course embedded in other equipment, in particular as the active components of calculators and other types of computer and related equipment.

2.5.4.5 Lloyd's Register's use of microcomputers in these indirect ways is likely to increase, but there is also in the authors' opinion considerable scope for their more direct application as aids to inspection and condition monitoring as well as to continuous checks for correct operation and safety of all types of equipment and structure. Many engineers will by now be familiar with the electronic micrometer, in which a microcomputer is used to achieve better repeatability and easier operation than a conventional micrometer. Further developments may well reverse the recent trend to quality assurance based on sampling and make 100% inspection economically feasible again, even in mass-production or hostile environments.

2.5.5 **Word processors (see Plate No. 4)**

These are similar in construction and capability to desk-top computers, with peripherals and software adapted to text processing. Extension of these facilities into the domain of the desk-top computer (and vice versa) is likely, and this will be useful to engineers and programmers who have to create and maintain detailed documentation. Software for word processing purposes will also be available in larger computers, whose power will permit the preparation, searching and indexing of large documents. Interfacing of word processors with mini and mainframe equipment and with other word processors is a trend which will shortly gather momentum.

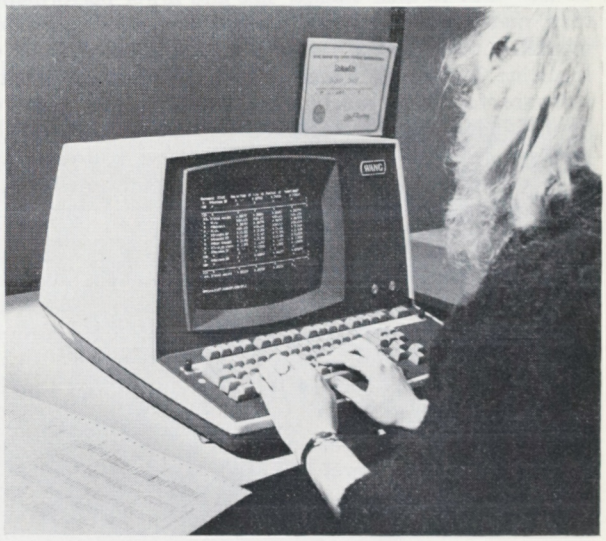


PLATE No. 4

One of Lloyd's Register's Wang word processors

2.5.6 **Intelligent Terminals (Plate No. 5)**

This term covers all terminals having some computing capability e.g. for data collection, for remote job entry or for enhancing the function of the terminal (e.g. providing scrolling, storage or formatting capability). Apart from the reduction in central processor load that carrying out such functions in the terminal achieves, this 'intelligence' can often substantially reduce the amount of data which has to be transferred between the terminal and the host machine since data can be transmitted in an encoded form. A number of intelligent terminals are in use in Lloyd's Register, some in locations remote from Headquarters. For example, in Lloyd's Register's Japan Offices, four of these devices are used for invoicing and administrative data collection, and at Lloyd's Register's Crawley Printing House they are use for keyboarding data for the Register Book.

PLATE NO. 5

An 'intelligent' terminal in use in Lloyd's Register's Accounts department

2.5.7 **Calculators**

The distinguishing features of calculators are their small physical size, portability, and low cost. Present calculators are limited in storage capacity and speed but both features are likely to increase. The limiting feature is likely to be the lack of a 'hard-copy' output device, although interfaces to permit calculators to be connected to typewriter terminals may be provided. Models available in the relatively near future will incorporate substantial amounts of storage capacity and may include exchangeable backing storage in the form of cassettes. These will be suitable for on-site data collection or on-site reference to pre-recorded information output from a larger computer, forming an electronic 'note-pad' or instruction manual.

2.5.8 **Special Purpose Computers**

A greater variety of special purpose computing elements is likely to arise during the next few years as the various functions of computing and data processing become better understood and differentiated. In particular, vector and array processors are already available which permit simultaneous arithmetic and logical functions on arrays of numbers, rather than one number at a time as on conventional computers. These may for example be applied to large matrix calculations, finite difference schemes, image processing and fast comparison of large volumes of data. Devices now on the market already allow arithmetic speeds up to 100 times faster than the IBM 370/158, and one computer to be constructed in the near future will have a speed 2000 times faster. Fast-Fourier Transform devices are special vector processors designed to perform forward and inverse Fourier Transforms very quickly. These are applied in Lloyd's Register to signal processing and in operational performance monitoring. Other special purpose devices are anticipated which will enable items in large bodies of stored data to be associated and retrieved very rapidly.

2.5.9 **Computing Networks and Communication of Data**

Improvements in communications over the last few years and those expected in the next decade will progressively reduce the difficulty and cost of communicating with computers at a distance, though the reductions in communication costs are unlikely to match reductions in computing costs in the foreseeable future. The use of such techniques is therefore likely to remain a question of the need for immediacy versus cost for the foreseeable future.

2.5.9.1 Telephone communication to computers, even across national boundaries, is increasingly an everyday tool, although the feasibility of this varies sharply from country to country. A number of large international computer networks are already in existence, providing access either to a central computer site, or to many computers on a one-to-one basis. Because of 'common carrier' postal restrictions, the latter type of network is as yet mainly restricted to research organisations.

2.5.9.2 However, facilities already exist within Lloyd's Register for direct connection of our mainframe computer to an international network, and this allows users in many parts of the world to run jobs on our machine and to transfer the results back into the network for further use. As the reliability of telex increases, this medium too will be more widely interfaced to computers and used for transmitting small amounts of data.

2.6 The spectrum of computing machinery is thus very wide. The price performance curves for equipment have however been remarkably consistent over a wide range of sizes in recent years, taking into account the cost and availability of software; that is, by the time packaging and software is taken into account, a unit of computing activity tends to cost a similar amount whether a large, or small computer is used. The universal adoption of silicon-chip technology for construction of computing equipment is likely to ensure that this trend continues in the near future. This generalisation is of course subject to local distortion where the job matches the machine particularly well or badly, and where one manufacturer temporarily 'steals a march' on another in pricing. It is thus important when selecting a computer or computing method to be aware of all the factors affecting the cost.

Medium	Speed Bytes/sec	Cost/Kilo Byte (pence)	
		Inland (UK)	Worldwide
Telex: PSN	5–6	8,00–23,00	45,00–275,00
Telephone line: Low volume (low speed—asynchronous)—PSN	10–120	0,17–10,00	17,50– 21,00
(high speed—synchronous)—PSN	120–220	0,08–1,00	2,00– 8,00
High volume (high speed—synchronous)—PW		0,08–0,32	2,00– 4,00

(PW denotes Private Wire, PSN denotes Public Switched Network)

FIG. 3

Typical data transmission costs

2.7 Besides cost, another factor affecting the choice of computer is of course the rate at which it can finish a job or react to a request. Broadly speaking, this is a function of size. but other factors, such as convenience and power of the language used to describe the problem and the method of input and output are also important. These factors are discussed in more detail below.

3. METHODS OF JOB SUBMISSION

3.1 Batch

This is the traditional method of communication with mainframe computers. Data to be submitted to the computer, together with the instructions for running the job, is prepared on cards, or input from an RJE or CRJE terminal. The data is then read into the computer where it is put into a queue, and the operating system then organises the processing of these jobs so as to optimise use of its central processor. For this reason, if the job requires extensive use of main storage or peripherals it may be in the queue for some time before being selected for processing. Output may be queued in the same way if the appropriate output devices are busy.

In some applications, particularly those involving large amounts of data or regular schedules, such delays do not present any inconvenience. For others, delay must be avoided, where possible. Some of the delays in batch-mode operation can be eliminated by the use of terminals to submit jobs direct to the computer. At Lloyd's Register there are a number of remote job entry terminals, both in the Headquarters building and at other locations. In addition, those jobs requiring limited input or output can be submitted from, and returned to, any of the teletype/video terminals at HQ.

3.2 Timesharing

It is a basic characteristic of a batch-mode operation that, having submitted his job to the system, the user will have no further contact until the job is completed. For work requiring extensive computing time, (and some large jobs can run for a matter of hours even on a large machine) there is no other sensible way to proceed. Even for small jobs, running the work in batch mode rather than sitting at a terminal or desk-top computer may save the engineer valuable time.

However there are many cases when the engineer will want to inspect intermediate results, and to input data during the course of the computation. In order to provide this 'interactive' facility to many users simultaneously, a technique known as timesharing is used. Under this regime, job processing is organised by the operating system of the computer so as to give each user apparently dedicated use of the computer. This is done by exploiting the fact that in an interactive situation the user's 'thinking time' is much greater than the computer time he requires.

In many computing environments, a change to a new application requires the user to 'sign on' to a different software system, or may even involve changing terminals. As a result, the user is often confronted with a number of different conventions or languages to learn, and speed and ease of communication is impaired. At Lloyd's Register, timesharing facilities available on the mainframe have been designed to provide facilities conversational remote job entry (see section 2.5.1.3), entry and editing of data, and calculation facilities, all within an integrated and secure computing environment, from a single terminal. These facilities are based upon the APLSV language processor (1) and have themselves been written in the APL language. Other packages written in this language allow word-processing, information retrieval and other tasks to be undertaken from the same terminal.

Such flexibility and continuity is an important ingredient in effective communication with a computer, and is one of the main reasons why this system was selected. Another reason was that it incorporated effective means for separating users from each other (so that their activities could not interfere with one another) and good back-up and re-start facilities for use in the event of communication or machine failure. Regrettably, many of these features have been absent from some of the time-sharing systems in widespread use.

It should perhaps be explained that the facilities in this system for transfer of jobs and data files to and from the batch environment in the computer are not restricted to the use of the APL language: FORTRAN or COBOL programs for example may be edited, compiled and run in this way.

4. MEDIA FOR COMMUNICATION WITH COMPUTERS

4.1 In the early days of computing, the media for communication with computers were few in number; in some cases all communication was via punched paper tape, in others via punched cards and printed output. Nowadays the number of different media has increased, and the opportunities for effective communication thereby improved, at the cost of a perhaps more bewildering choice.

4.2 It is perhaps most convenient to categorise these choices by reference to the form of the information to be communicated thus:

- Tabular data (i.e. lists)
- Text (i.e. unstructured data)
- Graphical images (graphs, line drawings, pictures)
- Electronic (i.e. from/to other machines)
- Other (e.g. audio, tactile etc)

Each of these can be used in an inward or outward direction (i.e. to, or from, the computer)

4.3 Tabular data

Tabular data has for a long time been the dominant member of this group. This arose partly as a consequence of the limited 'intelligence' of the software in computers and thus the need to organise data before presentation. The tabulation of data allows meaning to be implied rather than stated (e.g. 'the numbers in a given column represent wave height') and thus the descriptions of the data do not have to be transmitted and the volume of data transmitted can be kept to a minimum.

4.3.1 Media for communication of tabular information now include:

- Punched cards or Paper tape (0,5-1,5)
- Keyboards, (0,5-2)
- Magnetic media (10-1 million)
- Direct Electronic communication (from another machine) (10-5000)

The figures in brackets represent typical 'Bandwidths' in characters/second, taking into account the time taken to convert, check and read in the data, and represent the time per character of data from source to destination, through intermediate stages if necessary, including speed reduction due to batching processes, operator fatigue and so on.

4.3.1.1 The traditional media for data input, punched cards and paper tape, are still available. The main disadvantages of these methods of data input are that they involve an additional process between the data source and the machine, and are wasteful of raw materials. On the other hand, punched cards in particular have in the past proved a convenient medium for storage of input data since they are human- and machine-readable, robust and can be readily amended. As a method of two-way communication they are however poor, and thus do not allow the user to exploit more intelligent software to the full.

4.3.1.2 Direct entry of data through keyboard terminals, although equally slow, does allow interaction of this kind which can raise the effective bandwidth of communication. In particular, the use of 'intelligent' terminals allows the user to carry out corrections and rearrangements of the data to be input at a much higher rate and without wasting the resources of the computer itself. The terminals may also provide local data editing and validation facilities and limited storage, and in the case of visual displays allow inspection, editing, recall and submission of several lines of data at a time. Such terminals may have slow-speed printers attached, on which a copy of the data input may be preserved, although this is in human, not machine-readable form. Data cassettes or 'floppy discs' allowing the data to be stored in machine-readable form are also available but these media are of course not human-readable.

'Intelligent' terminals are more suitable than 'unintelligent' ones for input of tabular data as they can be programmed to accept, check and present successive elements of data in tabular form, the form of presentation and the checks applied being dependent on the position of the element in the input sequence. They can also prompt the user by describing the type of data to be entered next. Terminals of this kind are used in Lloyd's Register mainly for data-processing applications involving tabular input, such as invoicing and keyboarding of data for entry to our extensive files of shipping information (2). Desk-top computers with communicating capability can also be used as intelligent terminals.

4.3.1.3 As will be seen from the list in paragraph 4.3.1, the fastest method of getting data into a computer is from magnetic media such as discs or tapes. This presupposes that the data is already in machine-readable form. This medium is used in Lloyd's Register for transferring data in bulk from one computer to another, and for transporting data in bulk to archival storage for safe keeping. It is worth noting that despite advances in communication, the quickest way of transferring data from one machine to another in the vicinity is by physical transfer of a magnetic disk (up to 300 million characters) or a tape (typically 20 million characters). This of course applies whether the data is in tabular or non-tabular form.

4.3.1.4 Direct data communication to a computer is nowadays possible at a variety of speeds (see Fig. 3). The effectiveness of this medium depends upon the capacity and reliability of the telephone lines and equipment used and to some extent on the 'intelligence' of the equipment at both ends of the line, governing their ability to detect failures in communication, to retry and to inform the user of what has happened. The choice of method (e.g. private wire, public switched network) and speed depend upon the application and determines the cost.

So far, the only economical ways of transmitting data internationally are the Telex network (low data rate but can be interfaced to a computer) and the use of one of the computing networks mentioned earlier (up to 200 characters/sec). However, packet-switching and switched-circuit data networks are now being developed in many countries which promise to provide facilities suitable respectively for the transmission of small and larger quantities of data, and these should become available in the 1980s.

Within a country, the public switched telephone network may often be used (at up to 100 characters/sec) though this is often subject to interference.

Within a building, communication networks can be built to run at higher rates (up to 1 million characters/sec) but the higher rates are at present expensive. Here the application of closed-circuit television techniques may reduce the cost in the near future.

These techniques are all suitable for transmission of data either in tabular or non-tabular (text) form.

4.3.2 In an outward direction, suitable media for communication of tabular data are:

- Printed text (10-5000)
- Alphanumeric visual displays (intelligent or unintelligent) (10-500)
- Graphical displays or plotters (e.g. displaying bar-charts, contours or line drawings) (30-1000)
- Microfilm/microfiche (1000-2000)
- Magnetic media (10-1 million)
- Direct communications (10-5000)

Again the figures in brackets represent the speed of communication in characters/second.

4.3.2.1 Allowance should be made where appropriate for speed of searching and comprehension of the information once it has been displayed. Human beings are capable of searching their visual field very rapidly, but are much less effective when page-turning is involved. For this reason the figures above should be weighted heavily in favour of compact representation of the data. Graphical representations of data being two-dimensional in nature are much more compact than character representations. Graphical output from a computer therefore offers a powerful means of representation of tabular data in compact form. To search a 100-page listing for the largest value takes several orders of magnitude longer than to search for the same value in a contour plot. However the plot gives the information in a less precise form.

4.3.2.2 Printed tabulation, the traditional means of computer output, is being supplanted to a growing degree by more dynamic and less wasteful means of communication as the cost of terminal equipment falls and the cost of paper rises. However for applications where the results of a computation have to be referred to by several people, moved around in the course of work, or filed for future reference amongst other documents, it is likely to remain the most popular method for the forseeable future. An extensive range of equipment for computer output printing is available, ranging from typewriter-like devices through high speed line printers to laser printers capable of printing 10 000 lines per minute. Beside these high speed devices, which are capable of multi-font outputs and of generating forms including logos and rulings, recent developments include quiet printers using the electrostatic principle or heat sensitive paper rather than traditional impact printing. The latter is still the only method of producing multiple copies in one operation,

and does not need special paper or precautions to avoid fading of the image. For low speed work, variable fonts can be achieved with exchangeable type-ball or daisy wheel printers.

4.3.2.3 Alphanumeric visual display units (VDUs), allow rapid examination of tabular output, following which it may be printed or discarded. Because it avoids the need to print material which is to be discarded immediately it has been scanned, this is a better medium for interaction with a computer where small quantities of data are involved (see Fig. 9). In particular, debugging and correction of programs can often be speeded up substantially using this method, although it should be stressed that quick reaction to a logical fault is not necessarily the quickest way of resolving basic design errors in a program, and tends to militate against a methodical approach to program construction.

Despite the convenience of visual displays, where a permanent record of the user's questions and answers is required, a typewriter terminal may be preferable.

4.3.2.4 Recently, television receivers have been adopted for use as computer terminals. Their low cost will undoubtedly make them attractive for some applications, but the poor definition of the characters displayed limits the amount of text that can be shown at one time. On the other hand colour and block graphics can be used to enhance the amount of information conveyed, and these features are also appearing in other types of visual display unit. Displays with more extensive graphical capabilities are discussed in Section 4.5.

4.3.2.5 Output may be sent from a computer (sometimes via magnetic tape) to a photographic medium such as microfilm or microfiche. This technique, called Computer Output Microfilm, or COM, may be useful where the results need to be archived for reference in the distant future or where large numbers of copies of output need to be made for distribution over a wide geographical area. In LR an example of the former application is storage of accounting information and of the latter the distribution of up-to-date copies of ship survey information for Classification purposes (3). The expected improvements in communications in the next decade are likely to enable terminals to be introduced for the latter type of application.

Unfortunately the prospect of CIM (Computer Input Microfilm) from the early 1970's has not materialised and this medium remains human-readable only. Other media using the visual principle are under development, including the video-disc, which promises very high-density storage at low cost in the near future, but these are likely to be machine-readable only in the first instance. Clearly, a high speed, high density medium which is both machine and human-readable would have a considerable impact, since it would obviate much of the need for media conversion and communication between man and machine.

4.3.2.6 The remarks made in Section 4.3.1.3 and 4.3.1.4 regarding communication via magnetic media and direct electronic communication in an inward direction apply also to communication in an outward direction.

4.4 Text

Until the 1970's the entry, processing and storage of text in a computer was relatively uneconomical. Not only was storage in this form expensive, but processing costly and adequate software difficult to provide due to speed and space limitations within the machine. For example, proper hyphenation of text requires extensive look-up tables to be accessed at high speed and even now this is a specialist activity. However, storage and processing costs have now changed to such an extent that magnetic storage is competitive with paper as a medium for storing text, 'intelligent typewriters' (word processors) are becoming wide-spread, and the inclusion of text alongside numeric data is opening up new avenues of activity for the computer. The advent of Mass Storage systems with a capacity in the region of 10^{11} characters or more at a storage cost comparable with paper for the first time allows the storage of textual material in machine-readable form in large quantities to be contemplated.

4.4.1 As the capability of computers has progressed, it is now possible to relieve the user of more of the responsibility for marshalling and tabulating data to be input. In particular, data for numerical calculation may often be input as a string of text with suitable descriptive codes or names indicating the meaning of the following numbers, and these may be entered in any order convenient to the user. Such exploitation of the increasing power of computers is desirable for it enables the end user to concentrate upon his problem rather than the computer's limitations.

4.4.2 It is also becoming more feasible to search large amounts of textual data rapidly, and thus the need to encode data for easy retrieval is progressively being reduced. Efficient searching of really large amounts of textual data is however some years away and will depend upon new devices for storage and associative retrieval on the near horizon. Storage of data in or near its original form of course avoids the need to predict the type of inquiry to be made and thus, subject to performance limitations of the computer, removes restrictions on the range of enquiries.

4.4.3 Methods of input of textual data include all those listed for tabular data, with the exception that punched cards are not well suited to this medium. The technique of optical character recognition (OCR) should also be mentioned. This relies on a vidicon scanner (as used in facsimile transmission devices) to scan the characters on a sheet of paper which are then decoded to computer-readable form by a special-purpose character-recognition program. In present implementations such devices require human assistance, and are slow and subject to error except where special type-fonts are used on the input documents. This largely defeats the object since a keyboarding operation is necessary to prepare original documents in a clean enough form. In due course recognition of handwriting will no doubt be possible but is likely to be restricted to specialised applications due to the inherently small bandwidth of this medium of communication. A further method in limited use employs a touch sensitive pad, from which handwritten capital letters can be decoded by computer at a slow rate.

4.4.4 Methods of output of textual data also include those listed for tabular data, but it should be mentioned that the restricted font of many common computer input and output devices limits the range of characters that may be output directly from the computer. Increasing numbers of terminals and printing devices are now appearing with a larger character repertoire, but where the repertoire is extensive or the quality required is high, recourse must be made to the printing industry, which has developed extensive software and hardware for the purpose. Computer-held data can be converted to typesetting film via photographic film setters. Printing plates are then made and the work printed using conventional offset-litho techniques. This method is used within LR to prepare the Register of Ships. For very small amounts of text, special characters can be drawn on standard graphics terminals or plotters. This is the method used to annotate graphical images, e.g. drawings and plots produced on these devices.

4.5 Graphical Images

The man who coined the phrase 'a picture is worth a thousand words' did not specify the word-length of his computer! Nevertheless the truth of this adage has been extensively demonstrated within Lloyd's Register which was a pioneer of the use of advanced graphical computer techniques in the ship-building and offshore industries.

4.5.1 Initially, the justification for the development of the complicated software necessary stemmed from the fact that LR deals with large numbers of structural analyses, both of ships and offshore platforms. The preparation and listing of the large volumes of data necessary to describe the mathematical models of such structures for finite-element analysis proved an expensive and difficult task using punched cards and printed tabulations. Displaying the model structure on a screen allowed errors in the data to be seen almost immediately, whereas they would often be overlooked in a mass of tabulated data.

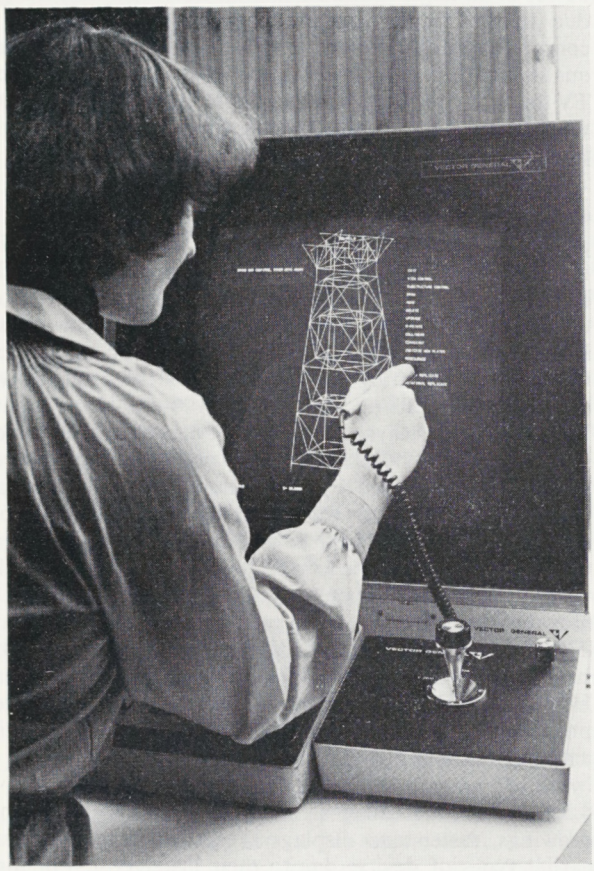


PLATE NO. 5

ICON in use

Vector General refresh graphics display and LR ICON software being used to create a finite element model of an offshore structure

4.5.2 Using a light-pen device it also became possible to point to parts of the structure to be identified to the computer, rather than having to key in their identification code or co-ordinates. (See Plate No. 5). The image of a structure could be rotated in three-dimensions at will and the model could then be viewed from any angle. Facilities for 'instant rotation' of this kind are still rare and this facility, though apparently a luxury, has proved surprisingly powerful as an aid to understanding of the image, especially where this is complicated.

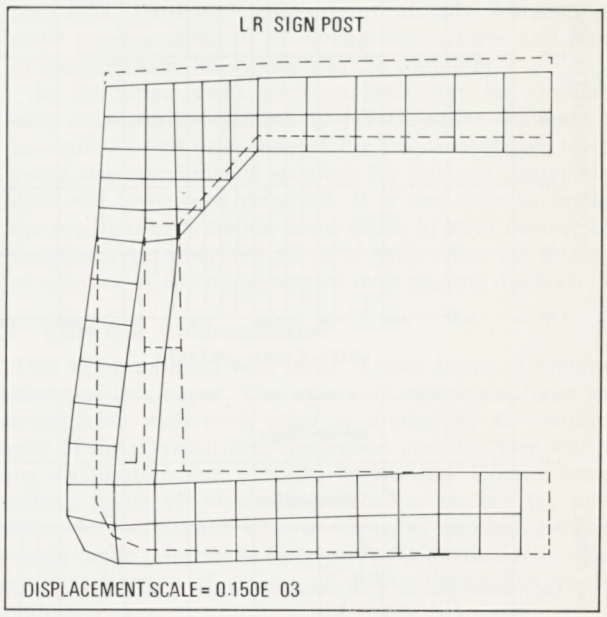


FIG. 4

Diagram produced by the LR SIGNPOST package

4.5.3 Apart from such sophisticated applications, graphical display and plotting equipment and software developed at Lloyd's Register has found extensive use in simpler applications involving the presentation of graphs and contours, stress-maps, thermal flow, curve-fitting, the preparation of illustrations for reports and scientific papers, visualisation of deflected structures and wave patterns, and the display of real-time data and spectral analyses from instrumented structures. (See Figs. 4 and 5).

4.5.4 Because of the high information density of graphic images, software for displaying and manipulating images is especially demanding in computing time and storage space, and displaying the images themselves demands a very high effective data transfer rate.

Output of graphic images is however a relatively simple task to arrange once the data is correctly organised in the computer. Devices for output of graphic images include:

Plotters (hard-copy devices)

- pen plotters
- electrostatic plotters

Graphical displays

- vector storage-tube displays (e.g. Tektronix)
- vector refresh displays (e.g. Vector General)
- raster-scan displays (e.g. Hewlett Packard 9845)

Devices for copying the image displayed on graphical displays

- Polaroid camera
- copier or matrix printer attached to the display

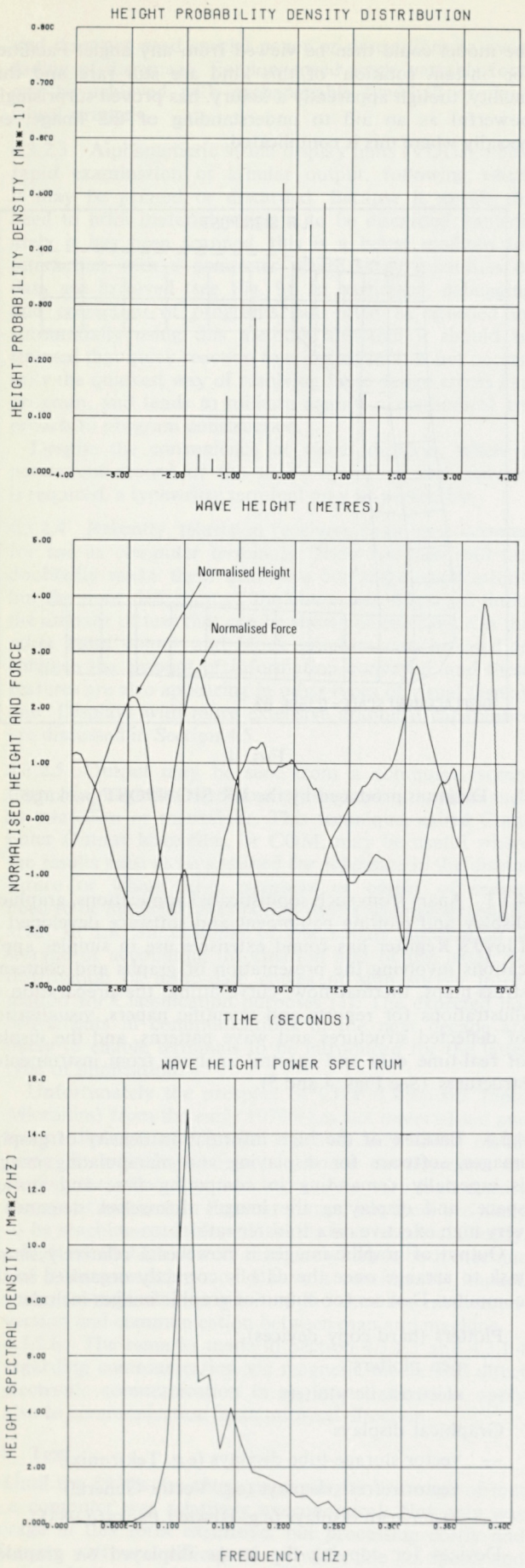


FIG. 5

Examples of graphs produced by the LR DAQPAK package

4.5.4.1 'Vector' devices such as plotters, storage tube displays and vector refresh graphics devices generate an image by directing the beam along straight lines from one point in a picture to the next, using analogue amplifiers and controls to achieve this. The most powerful of these devices also provide facilities for transforming the image co-ordinates, e.g. to provide apparent rotation or perspective projection of the image. Brightness can be varied to achieve a 'depth' effect or to highlight certain features, and other facilities are also available, such as flashing images, or in the case of plotters various line-widths and pen colours.

'Raster' devices such as electrostatic plotters and raster-scan displays on the other hand operate on the television scanning principle and images are generated as a set of picture points. In the more sophisticated of these displays a picture store is provided which relieves the main computer of the need to store the image once transmitted. This also enables part or all of the picture to be 'undrawn', a useful facility when modifications to the picture are needed. Straight-lines drawn on a raster device at an angle to the horizontal do not appear straight due to the regular spacing between picture points. A compromise has therefore to be achieved between picture quality and cost (high-resolution costs more). A typical TV picture has approximately 400×600 picture points, whereas for high quality 100 picture points or more to the inch are necessary.

4.5.4.2 Satisfactory speed comparisons are difficult to provide in the case of these devices as the effective information transfer rate depends to some extent on the content of the image displayed rather than the time taken to draw it. For electronic vector displays the drawing rate is high (typically 4000 cm/sec), whereas for mechanical devices slewing rates are limited by inertia and power available to speeds of the order of 100 cm/sec or below. Raster-scan displays of course operate at television speeds, but the number of new picture points altered per second is limited by the computer's ability to calculate their position (max. 0,1M picture points per second). Such ranges may be put in perspective by noting that the band-width necessary to display a moving television picture (with colour and shading) exceeds 10 megabits/second (1.2 million 8-bit characters/second). The rapid production of half-tone images is thus still beyond the capacity of most general-purpose computers. However, high quality images of this kind have been produced on an experimental basis using substantial amounts of computer time (6).

4.5.4.3 For line-images such as graphs and line-drawings, raster-scan displays are beginning to supplant earlier types of device, due to their lower cost. For high speed, high resolution applications where the image has to be changed dynamically, the vector refresh display is culate their position (max. 0,1M picture points per used, and this is the method employed in Lloyd's Register for the finite-element model work described above. For applications which do not require frequent updating of the image, storage tube devices are available. These have the advantage that the image is stored on the screen itself rather than in a computer store, so there is effectively no limit on the complexity of images that may be displayed other than the long drawing-time needed.

4.5.5 Devices for input of graphical images to a computer are much less well developed, since the process of graphical input implies interpretation of the meaning of the image.

Until now this part of the process has had to be accomplished by a human operator, using devices such as

Digitisers (See plate No. 6)
Light-pens
Cross-hair cursors

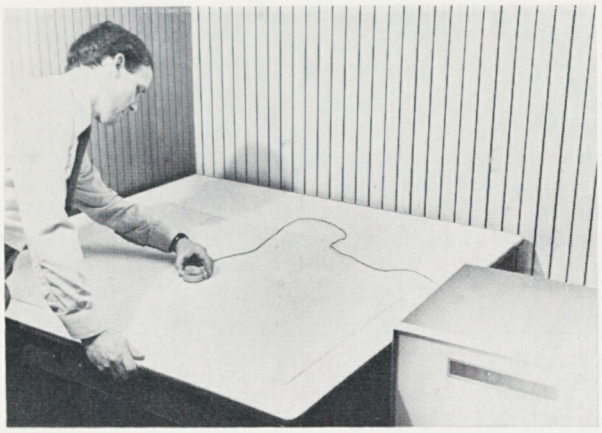


PLATE NO. 6

Digitiser in use

4.5.5.1 Digitisers consist of a table, to which the drawing to be digitised is attached, and a means of indicating to the computer the point whose co-ordinates are to be digitised. The user positions a sensor head (typically containing a magnetic, acoustical or pressure-sensitive transducer) over the required point on the drawing using cross-hairs or graticules, and presses a button, whereupon the co-ordinates are recorded in the computer on a machine readable medium. The rate at which this can be done is very low, typically 5 points/minute on average. and eyestrain and fatigue are obvious factors causing errors and inaccuracies. There is thus a high premium on software which can correctly infer intermediate points on the curves on a drawing from as little digitised data as possible, and Lloyd's Register has therefore invested in some sophisticated curve-fitting software for this purpose.

4.5.5.2 The remaining devices in this category, light-pens and cross-hair cursors, enable a point on a graphic display image to be identified. The light-pen is a hand-held device which sends a signal to the terminal displaying the picture whenever the display beam passes it. Extensive use of light-pens is fatiguing but they are quite rapid in use and allow easy selection from entries in a displayed 'menu' of commands or selection of points on a drawing. Alternatively a cross-hair cursor can be displayed and moved about the screen at the user's wish, via 'thumb-wheels', 'tracker balls', 'cursor keys' or 'joysticks' attached to the terminal. All of these devices are employed in various ways within Lloyd's Register for appropriate purposes. The drawbacks of all these devices are similar to those of digitising equipment.

4.5.5.3 The band-width available for graphical input is thus very small. However, Lloyd's Register receives much of its working data in the form of plans and lay-outs. Before this data can be acted on by a computer it must be transcribed in some way. Using conventional digitising equipment this is a tedious and expensive task.

4.5.5.4 In co-operation with the Imperial College of Science and Technology, Lloyd's Register is therefore investigating the possibility of connecting a television camera or other type of scanning device to a computer to digitise drawings, initially under human guidance, but eventually it is hoped largely automatically. A prototype system of this kind has been constructed, intended for hull shape take off for tonnage measurement, and has already produced promising results (Fig. 6). Work on both the software and the hardware for this system is proceeding and it is envisaged that the device, which is of comparatively low cost, will find a large number of applications. Particular applications already foreseen include photogrammetry of damaged structures and input of diagrammatic information to the computer.

In the longer term, such methods may be combined with character recognition to permit entire drawings to be read. At that point one of the major obstacles to the automatic searching of archives for relevant engineering data will have been removed. It is too soon to predict the eventual information band-width of such devices but the prototype described above already offers the promise of a factor of 100 improvement over existing methods (7).

4.6 Electronic Communication

This has been dealt with in its various forms in previous sections of this paper. The ease with which machines can communicate with each other is limited by the requirements of the physical interconnection and the 'protocol' or data organisation sent over the connection. Despite vested interests, many of which have acted to restrict the possibilities for connection of one device to another, progress is being made towards de facto and official standards which permit connection of devices of different manufacture, for example:

The RS232 (asynchronous) interface for low-speed devices
The IBM 2780 protocol for Remote Job Entry devices,
The IBM 370 channel interface for high speed device attachment,
The HDLC protocol (Digital Equipment Corporation) for network communication,
The X25 (protocol) and X21 (physical) interface standards for international packet switching networks.

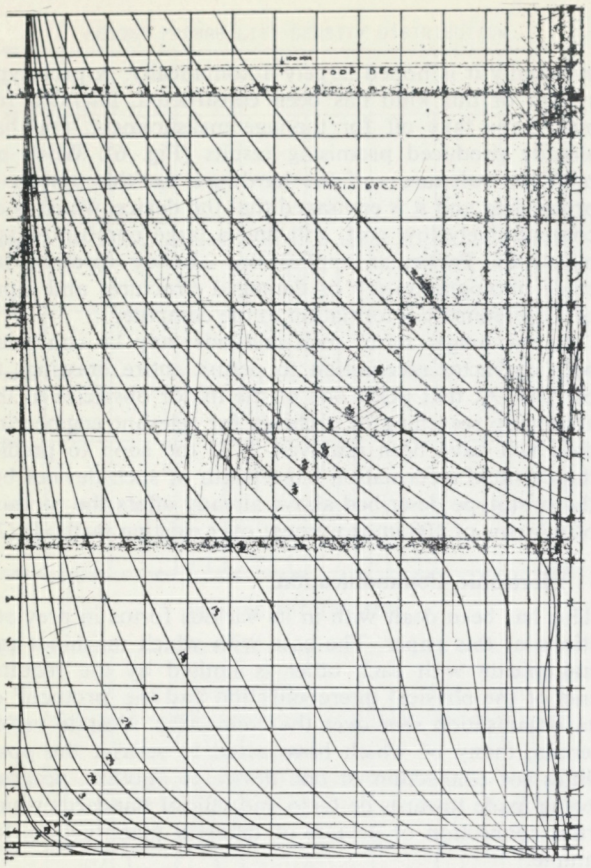
4.7 Other Forms of Communication with Computers

The only other form of communication with computers in widespread use is speech. Devices for translating computer data into the spoken word are now becoming quite sophisticated and in the near future are likely to be put to use in many new ways. An example is the Texas Instruments 'Speak and Spell' machine which shows what may be achieved in this field in the foreseeable future with 'micro-chip' technology. Voice recognition, too, is in its infancy but useful results have been reported. Perhaps the most obvious application for this will be in the field of dictation, although this is some years away. Both audio input and output are by nature likely to remain relatively low-bandwith channels of communication.

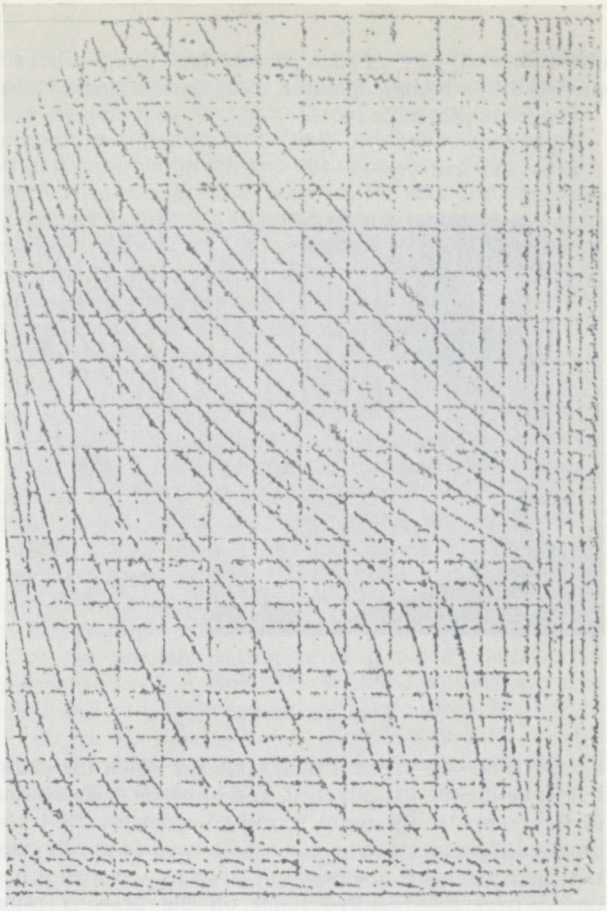
5. LANGUAGES FOR COMMUNICATION WITH COMPUTERS

5.1 Previous sections of this paper have dealt with the physical aspects of communicating with computers. In particular, it was shown that communication towards a computer is inherently slower than communication in the other direction. A means has therefore to be found to enable concise instructions to generate complex actions in a precise and controllable manner.

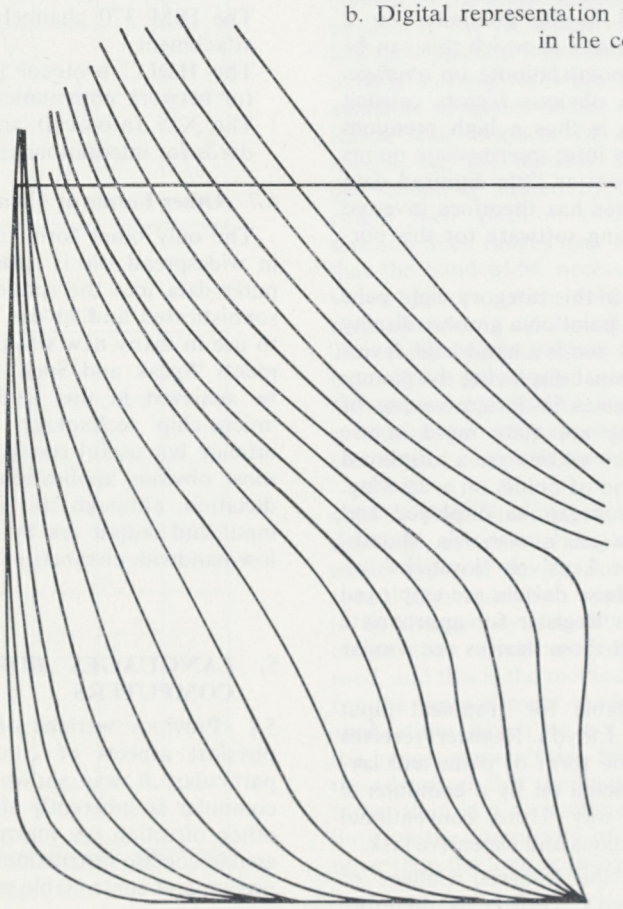
5.2 All communication with computers involves the use of some kind of 'language'. The greater the 'compression ratio' between the complexity of the instructions passed



a. The original engineering drawing (note imperfections)



b. Digital representation with no filtering as initially held in the computer's store



c. Computer plot of data extracted from b. by the computer under human control

FIG. 6

The use of video input techniques to digitise an engineering drawing

to a computer and its actions, the higher the level of the language is said to be. Computing languages are evolving slowly towards higher levels as ways are found to separate out the various logical components of the activities which users wish to carry out. This separation process has been found to be desirable not only so that users can understand the concepts readily but so that the instructions covering one aspect of the function can be specified independently of the others.

5.3 The first, 'low-level' computer languages dealt very much with the minutiae of computing such as the various error conditions that can arise when handling files, and decisions as to which storage locations and arithmetic registers were to be used were left to the user. Into this category fall 'machine' and 'Assembler' languages. Because such languages allow direct control over the way in which the computer handles a computation, they are still used for tasks where optimisation of speed or storage is important.

5.4 The first generation of 'high-level' languages, e.g. FORTRAN, ALGOL 60 and COBOL, allowed the user to concentrate largely on instructions relating to his problem rather than their layout in the store of the machine, and to define variables which are manipulated in much the same way as in mathematical expressions. However, the range of operations allowed in those languages was in general limited to simple operations to be performed one at a time, e.g.:

```
    A=B+C                          (FORTRAN)
or  ADD B TO C GIVING A.           (COBOL)
or  a:=b+c;                        (ALGOL 60)
```

Even at this level, the size and complexity of these languages became quite large and in the early 1970's a further language appeared, called BASIC because it was intended to be simple and easy to learn, having fewer facilities.

```
    LET A=B+C                      (BASIC)
```

in original BASIC has now almost universally been shortened to A=B+C as in FORTRAN.

5.5 FORTRAN and later BASIC found favour amongst engineers because these languages have a quasi-mathematical format and offer a good compromise between terseness and incomprehensibility on the one hand and long-windedness on the other. COBOL became widespread in business use because of its self-documenting qualities (similar to English) but is perhaps unnecessarily long-winded.

5.6 Due largely to the inertia effect generated by the need to maintain large numbers of programs written in these languages in the 1960's and 1970's, their development has continued, and they remain today the main avenue of communication with computers. ALGOL 60 was a casualty except in academic circles, largely because being intended to be machine-independent, its specification did not include effective verbs for input and output. A further language, PL1, available on IBM computers, was an attempt to combine the good features of all these languages, but did not raise the level of the programming task.

5.7 Since the late 1960's attempts have been made to extend the power of computing languages still further, The languages described above all incorporated effective means of segmenting a program, but with the exception of ALGOL 60 and PL1, did not provide a means of ensuring that these segments were logically distinct. The range of verbs included was also not exhaustive, for example none of these languages originally included a SORT verb. Some of these deficiences remain, while others have gradually been overcome, either within the frame of the original languages, or in later languages such as ALGOL 68, PASCAL, APL and FORTRAN 77, which have not yet gained such widespread acceptance.

5.8 A feature of all the languages described so far with the exception of APL is that they are essentially 'computer oriented' rather than 'application oriented' that is, they require the user to think in terms suited to the computer rather than the other way round. The ease with which computers can be used in the future will depend heavily on the extent to which the computer can react to instructions in the user's terminology. An example of such 'application oriented' languages is GIS (8), a package written in Assembler for information retrieval, widely used in LR for retrieving and tabulating information from large files of data. The SIFT package, written in APL and developed at LR (9), fulfils a similar role, e.g.

```
GET THOSEWITH GRT GREATERTHAN 50000
```

would retrieve records for ships over 50 000 Gross Registered Tons from a ship file. When considering programming languages for future use, it is important to choose a programming language with which it is possible to construct such 'user oriented' languages. This should if possible be machine-independent or 'portable' so that one does not lose the facility if the computing equipment is changed. Implementation of high performance tools of this kind in the earlier high-level languages COBOL and FORTRAN is, unfortunately, difficult as the range of commands available in these languages is not sufficiently powerful.

5.9 To run a program in a conventional high-level language like FORTRAN or COBOL normally requires that it first be compiled or translated into a lower-level language which can be interpreted efficiently by the machine. Recently, the cost/performance improvements in computers have enabled the designers of such languages to be more prodigal of computing resources and this for the first time permits the direct interpretation of computer languages with the flexibility this provides to stop, inspect and alter a program while it is running. Languages such as APL and BASIC were implemented with this ability in mind, while older languages in general do not allow this degree of flexibility. For the purpose of design checks, such flexibility may be dangerous, but for the other purposes it is a decided advantage.

5.10 The other feature of recent languages that should be mentioned is the incorporation of vector and array processing, e.g. in APL the statement:

```
    A←B+C
```

may be used to add two numbers together, to add two strings of numbers together (vectors) or to add two arrays with any number of dimensions together. Other operations permit other operations in matrix algebra, including inversion, to be specified very concisely. Extensions to both BASIC and FORTRAN for the same purpose have been made recently available for some machines, e.g.:

```
    MAT A=B+C
```

in HP9845 BASIC.

5.11 Unfortunately, the day of the single, portable, all-suitable computer language is not yet with us, nor are all existing languages available on any machine. Until then communication with computers will continue to require careful judgement. On the correct choice of computer language often depends not only the short-term success of a computer system, but its competitiveness in the future.

6. DIRECT/INDIRECT USE OF COMPUTERS

6.1 Many of the developments and devices discussed earlier in this paper have been directed towards making the computer more accessible to users, particularly engineers. At the same time, because of wider availability and application of computers and more relevant training in schools and universities, more engineers are now familiar with the techniques and concepts of computing than before. The advent of micro-computers is already causing a rapid change in the way control systems and other logical functions in engineering products are constructed. The logic is being implemented, not in hardware as before, but in software, where it can be changed and improved more quickly and cheaply. It is therefore to be expected that engineers will increasingly use computers in their daily work, of whatever engineering discipline this may be, and whatever their role.

However, just as electronic engineering has become a specialist discipline in electrical engineering because of the specialist knowledge required, so software engineering (i.e. systems analysis and programming) has become a separate discipline, with its own expertise, and the engineer must know when to take advantage of this.

6.2 If a mechanical engineer doing research were to devote his time to designing and building an oscilloscope it would be regarded as a misapplication of his time and a waste of money. Instead he uses an oscilloscope designed and maintained by electronic engineers, and if he encounters a problem he seeks their advice. On the other hand he must know enough about oscilloscopes to be able to operate them effectively and know when best to use them. Likewise, the designer of oscilloscopes must have a range of applications in mind if he is to achieve a useful end product.

6.3 In a similar way the best can only be obtained from computers if the skills and knowledge of the user engineer and the computing specialist are both used to the full. To use his own time effectively the engineer must often delegate significant aspects of the task of constructing and operating computer systems, and seek advice where appropriate. Those providing computer services must be competent to understand the aims of engineers who wish to use computers and provide appropriate basic software tools and hardware facilities for them to use. As in business systems the best results are obtained if engineering systems are discussed, designed and implemented as a co-operative activity between the user and the computing specialist. In that way both parties gain in knowledge, and a result is achieved which incorporates the knowledge of both, often quicker than if either tried to complete the task on his own.

6.4 Where computer systems or equipment are complex and individual engineers use them only infrequently, rather than the engineer using the equipment 'hands on', it may be more effective to train a specialist to extract or format the data or operate the equipment with the engineer 'looking over his shoulder'. A particular example of this in LR is the interactive graphics system, on which specialist operators develop great rapidity, and thus speed communication between the engineer and the computer.

7. ADDITIONAL FACTORS INVOLVED IN CHOICE OF EQUIPMENT

7.1 The earlier sections of this paper have illustrated the enormous variety of devices which have been developed in an attempt to enable men and computers to interact effectively. The pace of development shows no sign of slackening and is in danger of outstripping the capacity of industry to market and effectively use devices before they are outdated. In such a situation it must be recognised that despite competitive pressures there comes a point where the cost of change exceeds its benefit, and it is necessary to continue to use outdated equipment for a time until the benefits of change again outweigh the cost. The rate at which industries and individual companies market and adopt new devices and methods is thus likely to be dominated in the foreseeable future not by technological change but by economic inertia.

7.2 Another factor acting to reduce the rate of change is the necessity to preserve compatibility between new and old devices on the one hand, and between new computers and old programs on the other. The investment in software by most organisations now comfortably exceeds their investment in hardware. Accordingly there is a very strong argument for evolutionary rather than revolutionary changes in the computing field, with new devices able to interface to older computers, new computers able to run older programming languages and devices, and so on.

7.3 It would be pleasant to report that such evolution was leading rapidly towards a situation where the present widespread incompatibility between one computing device and the next and between different dialects of the same computing language would disappear, and the user would be free to choose the device and method most appropriate to his problem. Unfortunately, commercial pressures often act in the reverse direction and prompt suppliers to prevent interfacing of their equipment to that of other manufacturers. Thus despite the variety of devices available, great care is needed to select equipment and software which not only provides the facilities needed but will remain usable and competitive with new approaches and devices for more than a short time. Such a choice often involves careful timing, as a premature choice may severely reduce the lifetime of the software developed for the application.

The direction chosen by the manufacturers for the evolution of their equipment may also inhibit the user from moving in the direction he requires or even from communicating with the computer in the way he wishes, and there comes a point where revolutionary change, for example the adoption of a new type of computer using different languages and terminal devices, may be the only solution. Similar considerations apply to the choice and timing of changes to new items of basic software, e.g. operating systems, file-handling and terminal-handling software.

7.4 A further major consideration in the choice of equipment for communication with computers is reliability. The need for reliability varies considerably with the application, but broadly speaking the more rapid the response of the system is to be, the greater the reliability required. The availability of a computer as seen by the user depends not only on the physical integrity of the equipment, including the computer itself, its storage devices, peripheral equipment and communication links, but also the correctness of the software, the load on the computer and its components (which may cause unacceptable delays to occur at terminal devices if capacity is insufficient), correct operation of the computer and archival storage procedures, and environmental failures such as air conditioning and power supply.

7.5 Techniques for achieving high availability are now fairly well understood and at least one range of computers (TANDEM) has been designed with non-stop operation in mind. This is achieved by duplication of hardware and

software and rapid communication between computers to ensure that if a failure occurs in any component the process can continue elsewhere in the system. Although provision of this degree of availability is expensive it is becoming increasingly desirable not only in sensitive applications such as dynamic positioning systems for drill rigs and support vessels but also increasingly in office applications where the day-to-day work of many individuals may depend upon the availability of the computer. Unfortunately design for continued availability despite equipment software failure is still the exception rather than the rule though this may be expected to change over the next decade. Meanwhile worthwhile improvements in hardware reliability are occurring as the result of 'micro-chip' technology.

7.6 In the short term, the most practical step that can be taken to improve availability is to ensure that back-up equipment is readily available. This means that as far as possible new equipment selected should be compatible with existing equipment, that terminal equipment and software should be chosen to permit many types of application to be run from any terminal, and that the variety of computer terminal types, computing languages and basic software should be kept to a minimum consistent with achieving the required objective. In Lloyd's Register for this reason the introduction of computers, languages and operating systems which would discourage such flexibility has been avoided as far as possible, despite the fact that on occasions this has gone against individual preferences.

8. FUTURE DEVELOPMENTS AND THE NEEDS OF ENGINEERS IN LLOYD'S REGISTER

8. The level of communication required between engineers and computers depends heavily on the type of work in which the engineer is engaged. Within Lloyd's Register the application of computers by technical departments already varies from the extensive use of pocket calculators for ad hoc calculations to the use of extremely sophisticated input and output devices and large amounts of computing time for applications such as structural and thermal analysis. Not surprisingly, it is at the lower end of this range of power and complexity that the needs of engineers can be said to have been best met in the shortest time. At the next level up, the desk-top computer, the situation is also rapidly improving, with the recent introduction of graphical devices at relatively low cost for the first time.

8.2 A high proportion of the work of engineers involves interpreting and generating graphical images, as this is a more compact form of representation of physical data than text or tabulations. With the advent of these new lower-cost devices graphical communication with computers is therefore expected to assume a primary role as the power of computers at all levels increases and storage costs continue to fall.

8.3 Despite the advances already made and on the immediate horizon, there is however no prospect in view that the computing needs of engineers will be fully satisfied. Many types of application now stretch the capacity of even the largest computers to the full, and one has no difficulty in envisaging applications well beyond this scale. For example, detailed calculation of the fluid flow past an offshore platform in various conditions of wind and tide is at present well beyond the capacity of all but the largest computers and would be totally uneconomical in present conditions, however desirable. Likewise even the static analysis of structures at present often relies on approximations which are necessary solely because of limitations on computing capacity, speed and cost.

8.4 Studies of the dynamics of large structures, non-linear analyses, simulation, unsteady thermal flow, design optimisation, real-time data handling are other areas in which increased computer power would allow the engineer in Lloyd's Register to provide a better service. The advances expected in the next decade, in particular array processors and processor networks, will substantially reduce, if not eliminate, these barriers to better modelling of the physical world, and at the same time permit easier handling of the large amounts of data involved.

8.5 Storage and searching of large amounts of technical data will also become easier and more cost-effective than at present. The real barrier to such activities may well turn out to be the difficulty of collecting accurate and relevant data, but here too the micro-computer will be of considerable help in obtaining and filtering data obtained from experiments, field measurements and inspection.

8.6 During the same period the use of computers for word and text processing will increase rapidly and this is expected to ease significantly the work of the engineer in producing and amending his reports.

8.7 Progress in LR will continue on all these fronts in the next few years. Considerable advances have recently been made in providing a unified system for interactive access to the central computing complex. The interfacing of desk-top machines and intelligent terminals to this complex will shortly provide technical staff with access to a network providing a wide range of computing capacities and facilities for data storage. The complex will then grow by the addition of different processor types, storage and terminals as may be appropriate in the state of future technology. At the same time it will be connected to an ever wider variety of media for communication, which will in due course also allow Surveyors overseas to access the same facilities as those in Headquarters and to transmit, edit and receive data. Within Headquarters it will be necessary to provide a flexible and powerful means of intercommunication for data traffic so that terminals may be moved without rewiring the building to convenient locations as required. Portable terminals and the digital equivalent of pocket dictation and playback machines may also prove useful to the Surveyor in the field.

8.8 In conclusion, the last few years have seen astonishing advances in the range and performance of all types of computing equipment. As a result the variety of methods of communication with computers is now very wide. Many of these are already in use and available in Lloyd's Register. Nevertheless considerable further progress is required in techniques and languages for communication, in particular in the direction from humans to computers, before the computer can become an effortless extension of the mind of the engineer. This goal will be actively pursued.

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ON COMMUNICATING WITH COMPUTERS

by C. J. J. Beart, J. D. Short and G. K. Henderson

1. INTRODUCTION

1.1 From the start, the main advantage of computers over previous machines has been their versatility. Each new advance in computer technology has increased the range of tasks that can be undertaken with their help, and the pace of these advances has if anything increased in recent years. Yet even now it is sometimes difficult to achieve effective results from a computer in a reasonable time, as most of those who have used them will be aware.

1.2 There are several underlying reasons for this, some of which may not be apparent to the user who is not familiar with the details of computing. Among these barriers to effective use of a computer are:

the limitations of human beings in
- devising effective means to specify their requirements
- specifying their requirements
- foreseeing possible modes of failure
- storing and recalling large quantities of data reliably
- accuracy and consistency of action (e.g. due to fatigue)
- speed of communication and methods of communication (particularly in an outward direction)
- devising reliable mathematical models which avoid the pitfalls of approximation

and the limitations of computers in
- making effective use of past 'experience'
- interpreting imprecise commands or requests
- adaptability once programmed (they depend on human skill in forecasting requirements)
- methods of communication with human beings (particularly in an inward direction)
- rapid association of items embedded in large amounts of data
- reliability
- complexity of operation

1.3 Not only were these not appreciated in depth by the industry when computers were first introduced, but even now they have yet to be systematically categorised and studied. However, it will already be apparent from the above list that effective communication between man and machine, in particular from man to computer, is difficult to achieve. Not only is the effective bandwidth of communication low in this direction, but human beings have difficulty specifying their requirements precisely, while computers are poor at understanding imprecise statements. The technique of 'matching' circuit impedances to obtain maximum energy transfer will be familiar to electronic and acoustic engineers. Effective communication similarly requires the characteristics of source and destination to be matched, not only in bandwidth but in capacity and level of understanding.

1.4 The capacity of human beings for complete logical specification of their intentions is limited. Instead, having a long-term memory and an effective mechanism for association of ideas, they can often react correctly at short notice without reference to anything more than a rough statement of intent. On the other hand, computers, as they are constructed at present, are capable of following long sequences of instructions with guaranteed accuracy, but have little or no associative powers and therefore cannot react in a reasonable way to events which were not foreseen when the program was written. When preparing to use a computer it is therefore necessary to forecast correctly every eventuality which may occur during the execution of the program, not just to specify what is required.

1.5 Such eventualities may for instance result from:
- errors in specifying the procedure
- errors in the program
- errors in the data
- faults in the hardware (e.g. in a terminal or storage device)
- faults in the operating system or other basic software
- errors in operating instructions
- incorrect labelling or operation of archival storage
- insufficient storage or processing capacity
- external influences (e.g. failure of electrical supply or communication channel)

1.6 The amount of work necessary to achieve a given result with a computer can therefore be substantially greater than that required to solve the problem directly. In some cases this is a good argument for not using a computer; in many others the benefits, particularly in terms of speed and reliability, far outweigh the cost of the additional effort.

1.7 Of course, all of this additional effort should not be necessary every time a program is written. The effort expended in the last fifteen years by the suppliers of basic software (e.g. operating system programs, language compilers, packages for data storage and retrieval) has largely been aimed at reducing the user's need to concern himself with such matters, by providing proven tools for accomplishing common tasks and taking appropriate action when common faults arise. Unfortunately, each of these new tools has brought with it a new repertoire of commands, and the effect has too often been to increase the complexity of the computing activity rather than to ease the task of the user.

1.8 Over the same period, software costs have continued to rise, while the hardware costs have fallen. Thus there is now a much greater incentive than before for computer manufacturers to reduce the costs to the user of writing 'application software' i.e. of putting the computer to work. Fortunately, technology has enabled larger volumes of storage and greater processing power to be made available, and this has removed one of the main stumbling blocks to building more 'intelligence' into computers, that is the ability to take over more of the work involved in the man-computer dialogue. The software to exploit this capability to the full is still unfortunately some way in the future.

1.9 The dramatic reduction in the physical size of circuits and storage elements is also leading to an abrupt change in the man-machine relationship—whereas until now man has had to come to the machine, the machine has now begun to come to the man, in the shape of portable calculators, portable terminals, and shortly, portable bulk storage.

1.10 Furthermore, the cost of bulk storage of data on paper has risen substantially in recent years, and the cost of computer storage has already fallen to the point where it is beginning to look competitive with storage on paper (see Fig. 1). If this trend continues, as appears likely, effective methods of communication with computers will become a necessity for all of us.

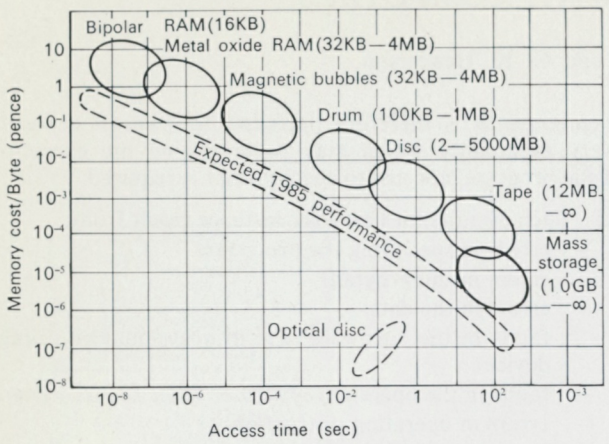


FIG. 1

Table of comparative costs of storage

1.11 It is therefore appropriate at this time to review the various aspects of communication with computers, and the developments which are now taking place in this field. Lloyd's Register has in recent years used computers for a wide range of tasks, and has been quick to make use of new techniques where these have been seen to be appropriate. Many of the techniques which will be in everyday use in the next decade can thus be illustrated by reference to applications or developments already taking place in this organisation. With this in mind the majority of examples are drawn from technical applications of computers within the Society, although many of the techniques will also be appropriate outside this field. It is our hope that this review will be helpful to existing and future users of computers within and outside Lloyd's Register, and in particular those who wish to use computers for engineering tasks.

2. MATCHING THE COMPUTER TO THE TASK

2.1 A pre-requisite for effective communication is clearly that the engineer uses the most appropriate type of computer for the job. The engineer requires different computing capabilities depending on the problem he has to solve. Whereas in the past he often had access to only one type of computer, the so-called 'mainframe' computer, there is now a bewildering variety of devices available, and more appear on the market every day.

2.2 To select the right computer for a given application demands a good understanding of the capabilities of each type of machine. Moreover to select the right spread of machines for future installation in an organisation demands not only a thorough understanding of the way the capabilities of such machines are evolving but also the ability to judge the effect these new capabilities will have on the applications themselves.

2.3 For example, the availability of suitable terminals and faster processors in the early 1970s allowed users to carry on a dialogue with computers for the first time, instead of being limited to communication over a scale of hours or days using punched cards or paper tape as an input medium. This in itself greatly enlarged the range of application of computers.

In the present decade, the advent of graphical communication from computers has already opened up many new fields of application. In the next five years further advances will certainly occur which will cause previously uneconomic applications to become economic in their turn. For example, array-processing techniques and cheaper storage will make computer simulation of the real time behaviour of structures and optimisation of design economically attractive for the first time.

2.4 Computers available today fall into the following categories:

Digital:

- Mainframe
- Mini (large mini-computers are nowadays called 'maxi' computers)
- Desk-Top
- Micro
- Word-processor
- 'Intelligent' terminal
- Calculator (hand-held, desk-top)
- Special-purpose (e.g. array processors, fast Fourier transform devices, associative storage devices)
- Computing networks (e.g. international networks)

Analogue:

- Electronic analogue computers (using operational amplifiers as integrators)
- Direct analogues (e.g. optical, mechanical)
- Spectral analysers

Device	Processor Speed (Millions of instructions per second)	Max I/O Rate (Bytes/sec)		
		To local peripherals ($\times 10^6$)	To local terminals/keyboards	To remote terminals
Calculators	0,0001	—	2	—
Word processor (Intelligent terminal)	0,001–0,03	0,1–0,5	10^{-1}	10–900 (limited by line speed)
Desk top computer	0,004–0,1	0,5–1	,,	,, ,,
Minicomputer	0,25	0,5–2	,,	,, ,,
Maxicomputer	0,35–0,9	1,0–8	,,	,, ,,
Mainframe computer	0,1–12	2,0–18	10^5	
Array processor	12–300	1,0–3	—	
Fastest projected computer	2000	?	?	

FIG. 2

Typical computer and communication speeds

Hybrid:
(incorporating analogue and digital components)
— Digital differential analysers
— Stochastic computers
— Analogue computers controlled by digital computers

2.5 Of these we are concerned here only with digital computers. All the above types of digital computer are already in use in Lloyd's Register. Each of them has particular characteristics which make it suitable for certain purposes and unsuitable for others. Typical characteristics of each type are tabulated in Fig. 2.

2.5.1 **Mainframe computers (Plate No. 1)**

These have the widest range of capability and are superior in processing performance and storage capacity to most other types. Sophisticated operating systems allow simultaneous use of the computer for a variety of purposes and by large numbers of users; alternatively the full power of the machine may be applied to one task at a time. Extensive on-line backing storage enables large quantities of data to be stored at low cost and accessed rapidly.

2.5.1.1 Applications involving high rates of input or output can be handled economically on these machines as the higher cost of fast input and output devices can be spread over many applications. Sophisticated devices of this kind do, however, need more protection, in the form of a controlled environment, than slower devices. Because of the wide variety of simultaneous demands on the computer, its work has to be carefully scheduled so on-line users may be subject to certain restrictions so that they do not adversely affect the service to other users. Because of the large software investment which can be justified by sales of such machines, the software available for them is extensive and they can be programmed in a large number of languages. However, due partly to this very versatility using one of these machines has in the past involved specialist expertise, and this can be a barrier to communication between the user and the machine.

2.5.1.2 More recently the power of these machines has been harnessed more effectively by devoting more of it to overcoming the problem of communication with the user. This enables more users to use the machine directly through terminals rather than through intermediaries, using less primitive computing 'languages' than in the past. One of the growing advantages of mainframes is also that their operating systems are increasingly incorporating measures for eliminating the security risks previously inherent in the use of a shared resource. As a result, the data stored in such a machine is safer and

PLATE NO. 1

The mainframe computer room at Lloyd's Register showing part of the IBM 370 installation.

less accessible to unauthorised users than if it were stored on paper, or cards or on a smaller machine.

2.5.1.3 The mainframe computer installed in Lloyd's Register is an IBM 370 Model 158 machine with 3 Megabytes of main storage, 3600 Megabytes of immediate-access disk storage, magnetic tapes and other peripheral equipment. Methods of communication with this computer now include:

- Card readers
- Line printers
- Graph plotters
- Remote Job Entry (RJE) terminals (for local or remote access through telephone lines). These are terminals with their own card readers, visual display units and printers, through which jobs may be submitted to the mainframe, and the results received and printed. Communication with the mainframe is in 'batch mode' that is, in bulk, rather than on an interactive basis, and jobs once submitted enter the normal batch job queues to await their turn for processing.
- Conversational Remote Job Entry (CRJE) terminals (local or remote). Similar to RJE, but data can be prepared, edited and stored using the power of the mainframe computer prior to submission. After the job has been run the output can be inspected in detail and further edited if required before printing.
- Interactive terminals (local or remote). These may be used to access the computer directly and to carry out computing tasks in 'conversational' fashion. Portable terminals are available which may, for example, be used 'on-site' during an engineering investigation or installed temporarily or permanently on customer sites. Interactive terminals of this kind may be used for much the same range of tasks as desk-top computers or word processors but allow the full power and storage capacity of a mainframe computer to be accessed as required. High speed communication channels (local only) permit very rapid transfer of data to and from local terminals (up to 800K characters/sec), but communication to external sites is limited by telephone speeds to 30-200 characters/sec depending on the terminal and line type.
- Facilities exist for connecting most types of computer, of any size, to the mainframe. In particular, this permits the connection of international computing networks to Lloyd's Register's mainframe computer, so that data may be prepared in other countries for submission to the computer and returned by the same means. Smaller special-purpose computers (e.g. for interactive graphics) may also be connected to the mainframe so that the characteristics of both can be used to best advantage. A further possibility is connection to the telex network.
- Magnetic tape. Data may be transmitted in bulk on magnetic tape to or from the computer. This medium is particularly suitable for bulk transfer of data in machine-readable form.
- Microfilm/Microfiche. Data may be converted to the form of microfilm or microfiche. This medium is useful for bulk reference data, where the number of enquiries per site is relatively low and communication costs are high but the data is not needed in machine-readable form.

2.5.1.4 Applications of the mainframe computer in Lloyd's Register are of many kinds, requiring substantial processing capacity, substantial storage, or a combination of both.

These include:

- Technical calculations, in particular large structural and thermal analyses, vibration studies, wave loading, stability and tonnage calculations.
- Information storage, maintenance and retrieval in such fields as Shipping Information Services, Technical Records, Staff Records, Classification and Accounts. All these functions involve the manipulation of very large data files and substantial quantities of input and output. Amongst this output is the copy for several substantial publications, including the Register Book.

2.5.2 Microcomputers (and Maxicomputers) (see Plate No. 2)

Minicomputers were originally developed for users who wished to construct their own software for one application in isolation, typically reduction or analysis of experimental data (a market area now covered by microcomputers). Subsequently they were developed and enlarged to the point where they were capable of many of the functions undertaken by mainframe computers. However, one feature contributing to the success of their low-cost design, the 16-bit word length, has until recently limited their speed and capacity. (Typical mainframes have a word length of 32 bits up to 60 bits, which enables larger areas of main storage to be addressed directly and greater arithmetic precision to be obtained in one machine cycle).

PLATE NO. 2
PDP/11 Minicomputer

2.5.2.1 Recently 'maxi-computers', i.e. mini-computers with a greater word length, have been appearing on the market. These machines are comparable in speed to the mainframe computers of the mid-1970s and have a greatly improved storage capacity. The development of software for these machines has followed a similar path to that for mainframe machines, some five years in arrears. For some purposes this presents an advantage in that a moderate amount of raw processing power can be obtained from such a machine at a cheaper price than from a mainframe. However, there is evidence that as the versatility of the manufacturer's software for

these machines increases, the cost differential between them and the mainframe computers will disappear. Already a reaction is evident from the mainframe computer manufacturers in the shape of reduction in central processor cost. The distinction between the high powered minicomputer and the low- to mid-range mainframe is thus fast disappearing.

2.5.2.2 At the lower end, minicomputers offer somewhat lower capacity than mainframes at somewhat lower cost. They are thus suitable for special purpose tasks (e.g. data collection, invoicing, small time sharing tasks) with up to, say, 20 users sharing a common set of software, two or three running independent software, or one user requiring more powerful computing facilities than a desk-top computer can provide. Typical applications in Lloyd's Register of the latter variety include the creation and checking of data for the analysis of ship and offshore structures, logging, filtering, display and analysis of signals from measuring devices (e.g. on-line monitoring of sea states using a minicomputer and appropriate transducers mounted on board a ship, analysis of wave-buoy and strain gauge-data) and processing of images generated by a T.V. camera. Multi-user applications in Lloyd's Register include invoicing and data-gathering for accountng purposes. Minicomputers installed include two PDP-11/45s, a PDP-11/34 and a Ventek 5500 computer.

2.5.2.3 Due to their smaller size and lower performance than mainframes, minicomputers require less environmental control and are easier to site. The amount of specialist knowledge required to operate and develop software for these machines is often greater than for mainframes as more software for minis tends to be 'home-grown'. Thus measure for measure, software support cost for minis is greater than for mainframes, where support costs can be spread over a larger number of users.

2.5.2.4 An even wider variety of terminals may be connected to minicomputers than to mainframes. Minis are thus often used as hosts for experimental configurations involving new terminal devices.
Terminal devices connected to minicomputers at Lloyd's Register include:

- 3-D refresh-graphics displays (Vector General 3D3)
- Storage-tube graphics displays (Tektronix)
- Alphanumeric visual display units (characters only)
- Typewriter terminals
- Analogue to digital converters (for reduction of experimental data)
- Fast Fourier transform devices
- Image scanners (T.V. camera)
- Computer-computer links to mainframe

2.5.2.5 The range of manufacturer-supported programming languages available on a minicomputer is more limited than on a mainframe but a large variety of experimental software is often available from other users.

2.5.3 Desk-top Computers (see Plate No. 3)

These have been developed from desk calculators and, as the result of recent advances in LSI (Large-scale Integration) circuitry, have now acquired some of the characteristics of larger computers. In addition they offer the advantage of small size and convenience in use.

2.5.3.1 The most recent type of desk-top computer to be used extensively at Lloyd's Register is the Hewlett-Packard 9845. In addition to a processor of considerable power this incorporates a raster-scan* display with resolution approximately 500×500 picture points. This machine is considered to mark the transition between the 1970s and the 1980s in terms of ease of use and compactness. Because of its powerful graphical display capabilities it is particularly suitable for engineering applications. Interfacing of these machines to more powerful computers with greater storage capacity will progressively give the user the best of both worlds in the fairly near future.

PLATE No. 3

An HP 9845 desk-top computer

2.5.3.2 Principal characteristics of desk-top computers are:

- Speed and main storage comparable with smaller mini-computers
- Limited backing storage, usually slow speed (but additional backing storage can often be attached, at additional cost)
- Single user
- Usually single language (normally BASIC or APL)
- No special environment needed—mains power supply
- No support staff required
- Simple to use

2.5.3.3 At Lloyd's Register desk-top computers are used increasingly both at HQ and at the outports for the relatively small scale calculations associated with routine plan approval, using software developed as part of the LR PASS system. In addition software for direct design calculations has been developed and is offered to clients for use on their desk-top machines. Other areas of application in Lloyd's Register include machinery design and plan approval, offshore structures and International Conventions work.

*See paragraph 4.5.4.1

2.5.3.4 There are many reasons for the popularity of desk-top machines, not the least of which is the apparently ready availability which they offer the engineer. The irony is of course that this popularity quickly reduces their availability, requiring the purchase of more and more machines. Although astonishingly cheap compared with their 1960's (and early 1970's) counterparts, they are still a factor of ten more expensive than terminals attached to a mini or mainframe computer.

2.5.3.5 During a typical hour-long session at a desk-top computer or terminal, the machine is probably usefully active for about 5 minutes. The other 55 minutes is user thinking time. In any situation there is thus a continuing case for using cheaper terminals if a larger computer is available, particularly if access to larger volumes of storage is required. On the other hand in countries where access to a larger computer is difficult these machines offer an excellent tool both to outport and the smaller shipbuilder.

2.5.4 **Microcomputers**

These machines embody the most recent developments in silicon chip technology, enabling very powerful processing facilities to be built into physically very small units. They are now beginning to be used in a very wide variety of fields, indeed all those fields in which logical decisions have to be made, for example, automatic controls in every industry from automobiles to washing machines, monitoring and inspection devices, and business equipment. Perhaps their best known role however is as the active component of pocket calculators. Increasingly, too, they are used as components of larger computers, from desk-top calculators to mainframes, and in that role have contributed largely to the reduction in size and price of such machines. They are particularly well suited to environments where small physical size or power consumption is important, e.g. in portable devices.

2.5.4.1 In all these fields, however, they need to be interfaced electrically to input, output and storage devices, packaged in a convenient manner and provided with software. The average user of computers who lacks the necessary facilities and knowledge of electronic engineering is unlikely to use these devices directly. Instead he will meet them in the guise of one of the other types of computer outlined here, or as part of an industrial component or business machine, and may well not even be aware that a microcomputer is involved.

2.5.4.2 While the cost of microcomputers is low, by the time they have been suitably interfaced, packaged and provided with input and output devices and software, the cost of the resulting machine is usually of the same order as desk-top computers or word processors or greater if software is developed for a one-off application. The only way in which the cost of the software can be brought down to the same order of magnitude as the machines themselves is to apply it to a mass market, as in automobiles, washing machines, calculators and the like.

2.5.4.3 The inverse relationship between cost on the one hand and the reliability and life of input and output devices must also be considered; a computer, however cheap, is of little use if the devices through which one communicates with it are unreliable.

2.5.4.4 Large numbers of microprocessors are already at work in Lloyd's Register. Almost all of these are of course embedded in other equipment, in particular as the active components of calculators and other types of computer and related equipment.

2.5.4.5 Lloyd's Register's use of microcomputers in these indirect ways is likely to increase, but there is also in the authors' opinion considerable scope for their more direct application as aids to inspection and condition monitoring as well as to continuous checks for correct operation and safety of all types of equipment and structure. Many engineers will by now be familiar with the electronic micrometer, in which a microcomputer is used to achieve better repeatability and easier operation than a conventional micrometer. Further developments may well reverse the recent trend to quality assurance based on sampling and make 100% inspection economically feasible again, even in mass-production or hostile environments.

2.5.5 **Word processors (see Plate No. 4)**

These are similar in construction and capability to desk-top computers, with peripherals and software adapted to text processing. Extension of these facilities into the domain of the desk-top computer (and vice versa) is likely, and this will be useful to engineers and programmers who have to create and maintain detailed documentation. Software for word processing purposes will also be available in larger computers, whose power will permit the preparation, searching and indexing of large documents. Interfacing of word processors with mini and mainframe equipment and with other word processors is a trend which will shortly gather momentum.

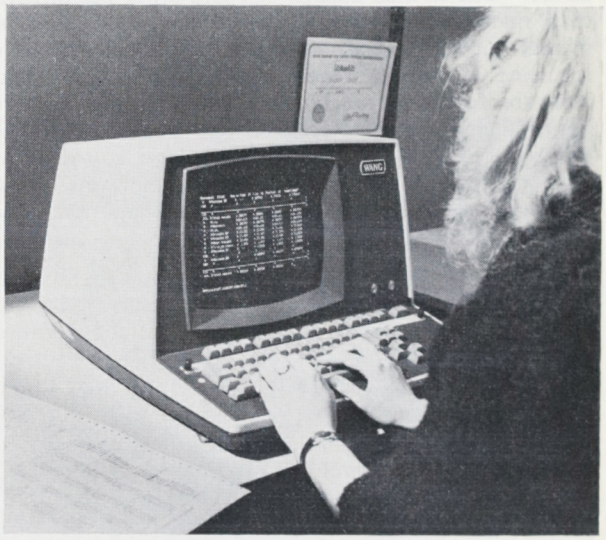


PLATE NO. 4

One of Lloyd's Register's Wang word processors

2.5.6 **Intelligent Terminals (Plate No. 5)**

This term covers all terminals having some computing capability e.g. for data collection, for remote job entry or for enhancing the function of the terminal (e.g. providing scrolling, storage or formatting capability). Apart from the reduction in central processor load that carrying out such functions in the terminal achieves, this 'intelligence' can often substantially reduce the amount of data which has to be transferred between the terminal and the host machine since data can be transmitted in an encoded form. A number of intelligent terminals are in use in Lloyd's Register, some in locations remote from Headquarters. For example, in Lloyd's Register's Japan Offices, four of these devices are used for invoicing and administrative data collection, and at Lloyd's Register's Crawley Printing House they are use for keyboarding data for the Register Book.

PLATE No. 5

An 'intelligent' terminal in use in Lloyd's Register's Accounts department

2.5.7 **Calculators**

The distinguishing features of calculators are their small physical size, portability, and low cost. Present calculators are limited in storage capacity and speed but both features are likely to increase. The limiting feature is likely to be the lack of a 'hard-copy' output device, although interfaces to permit calculators to be connected to typewriter terminals may be provided. Models available in the relatively near future will incorporate substantial amounts of storage capacity and may include exchangeable backing storage in the form of cassettes. These will be suitable for on-site data collection or on-site reference to pre-recorded information output from a larger computer, forming an electronic 'note-pad' or instruction manual.

2.5.8 **Special Purpose Computers**

A greater variety of special purpose computing elements is likely to arise during the next few years as the various functions of computing and data processing become better understood and differentiated. In particular, vector and array processors are already available which permit simultaneous arithmetic and logical functions on arrays of numbers, rather than one number at a time as on conventional computers. These may for example be applied to large matrix calculations, finite difference schemes, image processing and fast comparison of large volumes of data. Devices now on the market already allow arithmetic speeds up to 100 times faster than the IBM 370/158, and one computer to be constructed in the near future will have a speed 2000 times faster. Fast-Fourier Transform devices are special vector processors designed to perform forward and inverse Fourier Transforms very quickly. These are applied in Lloyd's Register to signal processing and in operational performance monitoring. Other special purpose devices are anticipated which will enable items in large bodies of stored data to be associated and retrieved very rapidly.

2.5.9 **Computing Networks and Communication of Data**

Improvements in communications over the last few years and those expected in the next decade will progressively reduce the difficulty and cost of communicating with computers at a distance, though the reductions in communication costs are unlikely to match reductions in computing costs in the foreseeable future. The use of such techniques is therefore likely to remain a question of the need for immediacy versus cost for the foreseeable future.

2.5.9.1 Telephone communication to computers, even across national boundaries, is increasingly an everyday tool, although the feasibility of this varies sharply from country to country. A number of large international computer networks are already in existence, providing access either to a central computer site, or to many computers on a one-to-one basis. Because of 'common carrier' postal restrictions, the latter type of network is as yet mainly restricted to research organisations.

2.5.9.2 However, facilities already exist within Lloyd's Register for direct connection of our mainframe computer to an international network, and this allows users in many parts of the world to run jobs on our machine and to transfer the results back into the network for further use. As the reliability of telex increases, this medium too will be more widely interfaced to computers and used for transmitting small amounts of data.

2.6 The spectrum of computing machinery is thus very wide. The price performance curves for equipment have however been remarkably consistent over a wide range of sizes in recent years, taking into account the cost and availability of software; that is, by the time packaging and software is taken into account, a unit of computing activity tends to cost a similar amount whether a large, or small computer is used. The universal adoption of silicon-chip technology for construction of computing equipment is likely to ensure that this trend continues in the near future. This generalisation is of course subject to local distortion where the job matches the machine particularly well or badly, and where one manufacturer temporarily 'steals a march' on another in pricing. It is thus important when selecting a computer or computing method to be aware of all the factors affecting the cost.

Medium	Speed Bytes/sec	Cost/Kilo Byte (pence)	
		Inland (UK)	Worldwide
Telex: PSN	5–6	8,00–23,00	45,00–275,00
Telephone line: Low volume (low speed—asynchronous)—PSN	10–120	0,17–10,00	17,50– 21,00
(high speed—synchronous)—PSN	120–220	0,08–1,00	2,00– 8,00
High volume (high speed—synchronous)—PW		0,08–0,32	2,00– 4,00

(PW denotes Private Wire, PSN denotes Public Switched Network)

FIG. 3

Typical data transmission costs

2.7 Besides cost, another factor affecting the choice of computer is of course the rate at which it can finish a job or react to a request. Broadly speaking, this is a function of size. but other factors, such as convenience and power of the language used to describe the problem and the method of input and output are also important. These factors are discussed in more detail below.

3. METHODS OF JOB SUBMISSION

3.1 Batch

This is the traditional method of communication with mainframe computers. Data to be submitted to the computer, together with the instructions for running the job, is prepared on cards, or input from an RJE or CRJE terminal. The data is then read into the computer where it is put into a queue, and the operating system then organises the processing of these jobs so as to optimise use of its central processor. For this reason, if the job requires extensive use of main storage or peripherals it may be in the queue for some time before being selected for processing. Output may be queued in the same way if the appropriate output devices are busy.

In some applications, particularly those involving large amounts of data or regular schedules, such delays do not present any inconvenience. For others, delay must be avoided, where possible. Some of the delays in batch-mode operation can be eliminated by the use of terminals to submit jobs direct to the computer. At Lloyd's Register there are a number of remote job entry terminals, both in the Headquarters building and at other locations. In addition, those jobs requiring limited input or output can be submitted from, and returned to, any of the teletype/video terminals at HQ.

3.2 Timesharing

It is a basic characteristic of a batch-mode operation that, having submitted his job to the system, the user will have no further contact until the job is completed. For work requiring extensive computing time, (and some large jobs can run for a matter of hours even on a large machine) there is no other sensible way to proceed. Even for small jobs, running the work in batch mode rather than sitting at a terminal or desk-top computer may save the engineer valuable time.

However there are many cases when the engineer will want to inspect intermediate results, and to input data during the course of the computation. In order to provide this 'interactive' facility to many users simultaneously, a technique known as timesharing is used. Under this regime, job processing is organised by the operating system of the computer so as to give each user apparently dedicated use of the computer. This is done by exploiting the fact that in an interactive situation the user's 'thinking time' is much greater than the computer time he requires.

In many computing environments, a change to a new application requires the user to 'sign on' to a different software system, or may even involve changing terminals. As a result, the user is often confronted with a number of different conventions or languages to learn, and speed and ease of communication is impaired. At Lloyd's Register, timesharing facilities available on the mainframe have been designed to provide facilities conversational remote job entry (see section 2.5.1.3), entry and editing of data, and calculation facilities, all within an integrated and secure computing environment, from a single terminal. These facilities are based upon the APLSV language processor (1) and have themselves been written in the APL language. Other packages written in this language allow word-processing, information retrieval and other tasks to be undertaken from the same terminal.

Such flexibility and continuity is an important ingredient in effective communication with a computer, and is one of the main reasons why this system was selected. Another reason was that it incorporated effective means for separating users from each other (so that their activities could not interfere with one another) and good back-up and re-start facilities for use in the event of communication or machine failure. Regrettably, many of these features have been absent from some of the time-sharing systems in widespread use.

It should perhaps be explained that the facilities in this system for transfer of jobs and data files to and from the batch environment in the computer are not restricted to the use of the APL language: FORTRAN or COBOL programs for example may be edited, compiled and run in this way.

4. MEDIA FOR COMMUNICATION WITH COMPUTERS

4.1 In the early days of computing, the media for communication with computers were few in number; in some cases all communication was via punched paper tape, in others via punched cards and printed output. Nowadays the number of different media has increased, and the opportunities for effective communication thereby improved, at the cost of a perhaps more bewildering choice.

4.2 It is perhaps most convenient to categorise these choices by reference to the form of the information to be communicated thus:

- Tabular data (i.e. lists)
- Text (i.e. unstructured data)
- Graphical images (graphs, line drawings, pictures)
- Electronic (i.e. from/to other machines)
- Other (e.g. audio, tactile etc)

Each of these can be used in an inward or outward direction (i.e. to, or from, the computer)

4.3 Tabular data

Tabular data has for a long time been the dominant member of this group. This arose partly as a consequence of the limited 'intelligence' of the software in computers and thus the need to organise data before presentation. The tabulation of data allows meaning to be implied rather than stated (e.g. 'the numbers in a given column represent wave height') and thus the descriptions of the data do not have to be transmitted and the volume of data transmitted can be kept to a minimum.

4.3.1 Media for communication of tabular information now include:

- Punched cards or Paper tape (0,5-1,5)
- Keyboards, (0,5-2)
- Magnetic media (10-1 million)
- Direct Electronic communication (from another machine) (10-5000)

The figures in brackets represent typical 'Bandwidths' in characters/second, taking into account the time taken to convert, check and read in the data, and represent the time per character of data from source to destination, through intermediate stages if necessary, including speed reduction due to batching processes, operator fatigue and so on.

4.3.1.1 The traditional media for data input, punched cards and paper tape, are still available. The main disadvantages of these methods of data input are that they involve an additional process between the data source and the machine, and are wasteful of raw materials. On the other hand, punched cards in particular have in the past proved a convenient medium for storage of input data since they are human- and machine-readable, robust and can be readily amended. As a method of two-way communication they are however poor, and thus do not allow the user to exploit more intelligent software to the full.

4.3.1.2 Direct entry of data through keyboard terminals, although equally slow, does allow interaction of this kind which can raise the effective bandwidth of communication. In particular, the use of 'intelligent' terminals allows the user to carry out corrections and rearrangements of the data to be input at a much higher rate and without wasting the resources of the computer itself. The terminals may also provide local data editing and validation facilities and limited storage, and in the case of visual displays allow inspection, editing, recall and submission of several lines of data at a time. Such terminals may have slow-speed printers attached, on which a copy of the data input may be preserved, although this is in human, not machine-readable form. Data cassettes or 'floppy discs' allowing the data to be stored in machine-readable form are also available but these media are of course not human-readable.

'Intelligent' terminals are more suitable than 'unintelligent' ones for input of tabular data as they can be programmed to accept, check and present successive elements of data in tabular form, the form of presentation and the checks applied being dependent on the position of the element in the input sequence. They can also prompt the user by describing the type of data to be entered next. Terminals of this kind are used in Lloyd's Register mainly for data-processing applications involving tabular input, such as invoicing and keyboarding of data for entry to our extensive files of shipping information (2). Desk-top computers with communicating capability can also be used as intelligent terminals.

4.3.1.3 As will be seen from the list in paragraph 4.3.1, the fastest method of getting data into a computer is from magnetic media such as discs or tapes. This presupposes that the data is already in machine-readable form. This medium is used in Lloyd's Register for transferring data in bulk from one computer to another, and for transporting data in bulk to archival storage for safe keeping. It is worth noting that despite advances in communication, the quickest way of transferring data from one machine to another in the vicinity is by physical transfer of a magnetic disk (up to 300 million characters) or a tape (typically 20 million characters). This of course applies whether the data is in tabular or non-tabular form.

4.3.1.4 Direct data communication to a computer is nowadays possible at a variety of speeds (see Fig. 3). The effectiveness of this medium depends upon the capacity and reliability of the telephone lines and equipment used and to some extent on the 'intelligence' of the equipment at both ends of the line, governing their ability to detect failures in communication, to retry and to inform the user of what has happened. The choice of method (e.g. private wire, public switched network) and speed depend upon the application and determines the cost.

So far, the only economical ways of transmitting data internationally are the Telex network (low data rate but can be interfaced to a computer) and the use of one of the computing networks mentioned earlier (up to 200 characters/sec). However, packet-switching and switched-circuit data networks are now being developed in many countries which promise to provide facilities suitable respectively for the transmission of small and larger quantities of data, and these should become available in the 1980s.

Within a country, the public switched telephone network may often be used (at up to 100 characters/sec) though this is often subject to interference.

Within a building, communication networks can be built to run at higher rates (up to 1 million characters/sec) but the higher rates are at present expensive. Here the application of closed-circuit television techniques may reduce the cost in the near future.

These techniques are all suitable for transmission of data either in tabular or non-tabular (text) form.

4.3.2 In an outward direction, suitable media for communication of tabular data are:

- Printed text (10-5000)
- Alphanumeric visual displays (intelligent or unintelligent) (10-500)
- Graphical displays or plotters (e.g. displaying bar-charts, contours or line drawings) (30-1000)
- Microfilm/microfiche (1000-2000)
- Magnetic media (10-1 million)
- Direct communications (10-5000)

Again the figures in brackets represent the speed of communication in characters/second.

4.3.2.1 Allowance should be made where appropriate for speed of searching and comprehension of the information once it has been displayed. Human beings are capable of searching their visual field very rapidly, but are much less effective when page-turning is involved. For this reason the figures above should be weighted heavily in favour of compact representation of the data. Graphical representations of data being two-dimensional in nature are much more compact than character representations. Graphical output from a computer therefore offers a powerful means of representation of tabular data in compact form. To search a 100-page listing for the largest value takes several orders of magnitude longer than to search for the same value in a contour plot. However the plot gives the information in a less precise form.

4.3.2.2 Printed tabulation, the traditional means of computer output, is being supplanted to a growing degree by more dynamic and less wasteful means of communication as the cost of terminal equipment falls and the cost of paper rises. However for applications where the results of a computation have to be referred to by several people, moved around in the course of work, or filed for future reference amongst other documents, it is likely to remain the most popular method for the forseeable future. An extensive range of equipment for computer output printing is available, ranging from typewriter-like devices through high speed line printers to laser printers capable of printing 10 000 lines per minute. Beside these high speed devices, which are capable of multi-font outputs and of generating forms including logos and rulings, recent developments include quiet printers using the electrostatic principle or heat sensitive paper rather than traditional impact printing. The latter is still the only method of producing multiple copies in one operation,

and does not need special paper or precautions to avoid fading of the image. For low speed work, variable fonts can be achieved with exchangeable type-ball or daisy wheel printers.

4.3.2.3 Alphanumeric visual display units (VDUs), allow rapid examination of tabular output, following which it may be printed or discarded. Because it avoids the need to print material which is to be discarded immediately it has been scanned, this is a better medium for interaction with a computer where small quantities of data are involved (see Fig. 9). In particular, debugging and correction of programs can often be speeded up substantially using this method, although it should be stressed that quick reaction to a logical fault is not necessarily the quickest way of resolving basic design errors in a program, and tends to militate against a methodical approach to program construction.

Despite the convenience of visual displays, where a permanent record of the user's questions and answers is required, a typewriter terminal may be preferable.

4.3.2.4 Recently, television receivers have been adopted for use as computer terminals. Their low cost will undoubtedly make them attractive for some applications, but the poor definition of the characters displayed limits the amount of text that can be shown at one time. On the other hand colour and block graphics can be used to enhance the amount of information conveyed, and these features are also appearing in other types of visual display unit. Displays with more extensive graphical capabilities are discussed in Section 4.5.

4.3.2.5 Output may be sent from a computer (sometimes via magnetic tape) to a photographic medium such as microfilm or microfiche. This technique, called Computer Output Microfilm, or COM, may be useful where the results need to be archived for reference in the distant future or where large numbers of copies of output need to be made for distribution over a wide geographical area. In LR an example of the former application is storage of accounting information and of the latter the distribution of up-to-date copies of ship survey information for Classification purposes (3). The expected improvements in communications in the next decade are likely to enable terminals to be introduced for the latter type of application.

Unfortunately the prospect of CIM (Computer Input Microfilm) from the early 1970's has not materialised and this medium remains human-readable only. Other media using the visual principle are under development, including the video-disc, which promises very high-density storage at low cost in the near future, but these are likely to be machine-readable only in the first instance. Clearly, a high speed, high density medium which is both machine and human-readable would have a considerable impact, since it would obviate much of the need for media conversion and communication between man and machine.

4.3.2.6 The remarks made in Section 4.3.1.3 and 4.3.1.4 regarding communication via magnetic media and direct electronic communication in an inward direction apply also to communication in an outward direction.

4.4 Text

Until the 1970's the entry, processing and storage of text in a computer was relatively uneconomical. Not only was storage in this form expensive, but processing costly and adequate software difficult to provide due to speed and space limitations within the machine. For example, proper hyphenation of text requires extensive look-up tables to be accessed at high speed and even now this is a specialist activity. However, storage and processing costs have now changed to such an extent that magnetic storage is competitive with paper as a medium for storing text, 'intelligent typewriters' (word processors) are becoming wide-spread, and the inclusion of text alongside numeric data is opening up new avenues of activity for the computer. The advent of Mass Storage systems with a capacity in the region of 10^{11} characters or more at a storage cost comparable with paper for the first time allows the storage of textual material in machine-readable form in large quantities to be contemplated.

4.4.1 As the capability of computers has progressed, it is now possible to relieve the user of more of the responsibility for marshalling and tabulating data to be input. In particular, data for numerical calculation may often be input as a string of text with suitable descriptive codes or names indicating the meaning of the following numbers, and these may be entered in any order convenient to the user. Such exploitation of the increasing power of computers is desirable for it enables the end user to concentrate upon his problem rather than the computer's limitations.

4.4.2 It is also becoming more feasible to search large amounts of textual data rapidly, and thus the need to encode data for easy retrieval is progressively being reduced. Efficient searching of really large amounts of textual data is however some years away and will depend upon new devices for storage and associative retrieval on the near horizon. Storage of data in or near its original form of course avoids the need to predict the type of inquiry to be made and thus, subject to performance limitations of the computer, removes restrictions on the range of enquiries.

4.4.3 Methods of input of textual data include all those listed for tabular data, with the exception that punched cards are not well suited to this medium. The technique of optical character recognition (OCR) should also be mentioned. This relies on a vidicon scanner (as used in facsimile transmission devices) to scan the characters on a sheet of paper which are then decoded to computer-readable form by a special-purpose character-recognition program. In present implementations such devices require human assistance, and are slow and subject to error except where special type-fonts are used on the input documents. This largely defeats the object since a keyboarding operation is necessary to prepare original documents in a clean enough form. In due course recognition of handwriting will no doubt be possible but is likely to be restricted to specialised applications due to the inherently small bandwidth of this medium of communication. A further method in limited use employs a touch sensitive pad, from which handwritten capital letters can be decoded by computer at a slow rate.

4.4.4 Methods of output of textual data also include those listed for tabular data, but it should be mentioned that the restricted font of many common computer input and output devices limits the range of characters that may be output directly from the computer. Increasing numbers of terminals and printing devices are now appearing with a larger character repertoire, but where the repertoire is extensive or the quality required is high, recourse must be made to the printing industry, which has developed extensive software and hardware for the purpose. Computer-held data can be converted to typesetting film via photographic film setters. Printing plates are then made and the work printed using conventional offset-litho techniques. This method is used within LR to prepare the Register of Ships. For very small amounts of text, special characters can be drawn on standard graphics terminals or plotters. This is the method used to annotate graphical images, e.g. drawings and plots produced on these devices.

4.5 Graphical Images

The man who coined the phrase 'a picture is worth a thousand words' did not specify the word-length of his computer! Nevertheless the truth of this adage has been extensively demonstrated within Lloyd's Register which was a pioneer of the use of advanced graphical computer techniques in the ship-building and offshore industries.

4.5.1 Initially, the justification for the development of the complicated software necessary stemmed from the fact that LR deals with large numbers of structural analyses, both of ships and offshore platforms. The preparation and listing of the large volumes of data necessary to describe the mathematical models of such structures for finite-element analysis proved an expensive and difficult task using punched cards and printed tabulations. Displaying the model structure on a screen allowed errors in the data to be seen almost immediately, whereas they would often be overlooked in a mass of tabulated data.

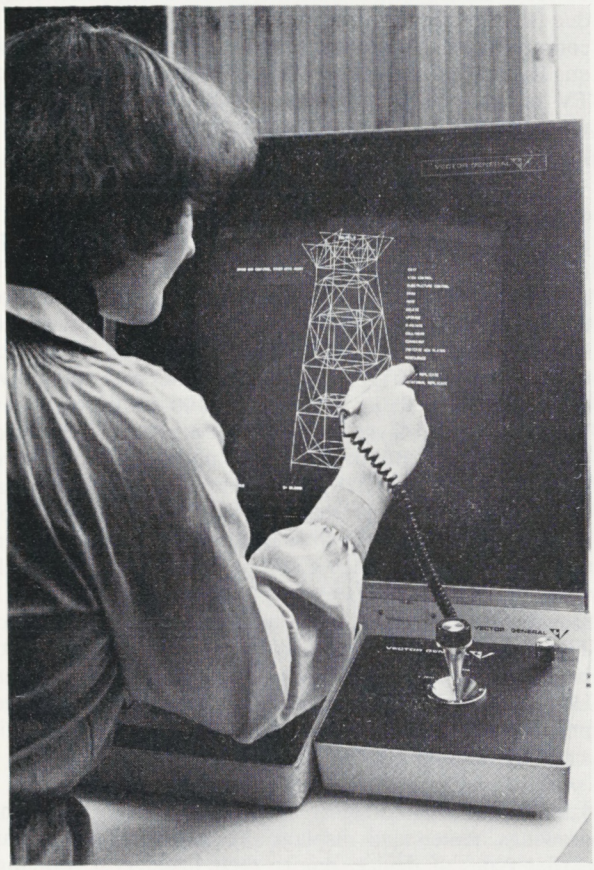


PLATE No. 5

ICON in use

Vector General refresh graphics display and LR ICON software being used to create a finite element model of an offshore structure

4.5.2 Using a light-pen device it also became possible to point to parts of the structure to be identified to the computer, rather than having to key in their identification code or co-ordinates. (See Plate No. 5). The image of a structure could be rotated in three-dimensions at will and the model could then be viewed from any angle. Facilities for 'instant rotation' of this kind are still rare and this facility, though apparently a luxury, has proved surprisingly powerful as an aid to understanding of the image, especially where this is complicated.

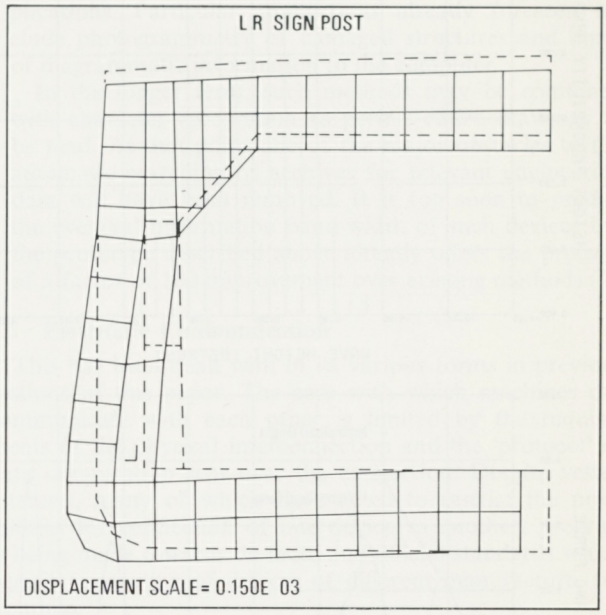


FIG. 4

Diagram produced by the LR SIGNPOST package

4.5.3 Apart from such sophisticated applications, graphical display and plotting equipment and software developed at Lloyd's Register has found extensive use in simpler applications involving the presentation of graphs and contours, stress-maps, thermal flow, curve-fitting, the preparation of illustrations for reports and scientific papers, visualisation of deflected structures and wave patterns, and the display of real-time data and spectral analyses from instrumented structures. (See Figs. 4 and 5).

4.5.4 Because of the high information density of graphic images, software for displaying and manipulating images is especially demanding in computing time and storage space, and displaying the images themselves demands a very high effective data transfer rate.

Output of graphic images is however a relatively simple task to arrange once the data is correctly organised in the computer. Devices for output of graphic images include:

Plotters (hard-copy devices)

- pen plotters
- electrostatic plotters

Graphical displays

- vector storage-tube displays (e.g. Tektronix)
- vector refresh displays (e.g. Vector General)
- raster-scan displays (e.g. Hewlett Packard 9845)

Devices for copying the image displayed on graphical displays

- Polaroid camera
- copier or matrix printer attached to the display

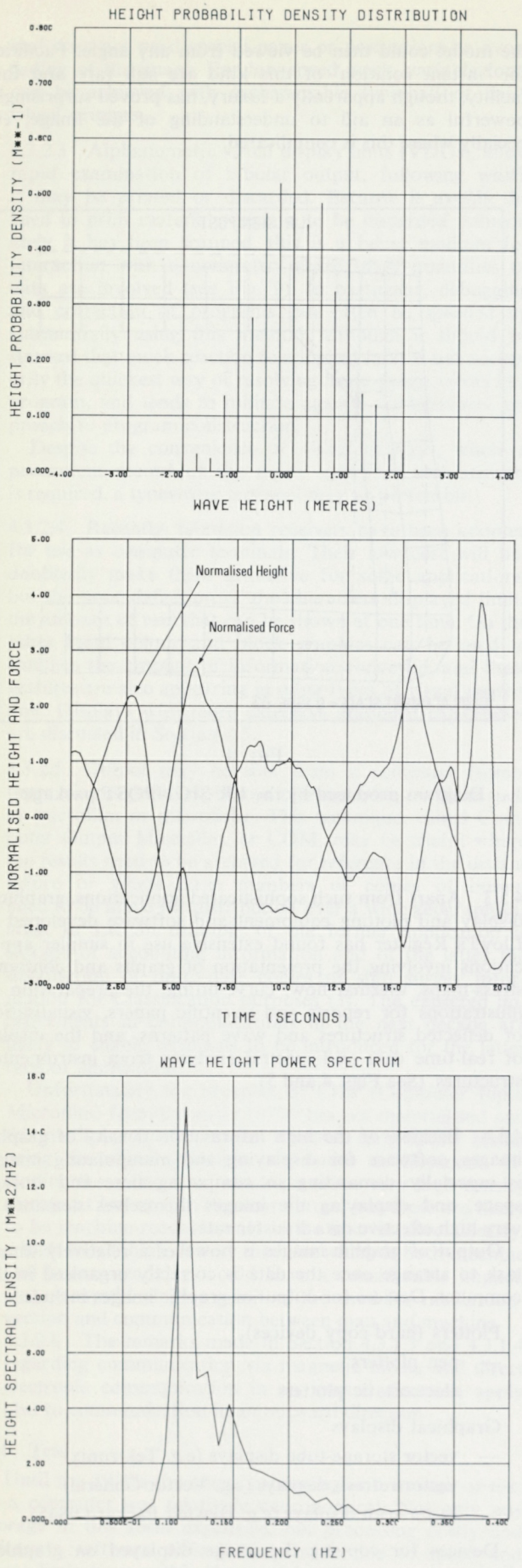


FIG. 5

Examples of graphs produced by the LR DAQPAK package

4.5.4.1 'Vector' devices such as plotters, storage tube displays and vector refresh graphics devices generate an image by directing the beam along straight lines from one point in a picture to the next, using analogue amplifiers and controls to achieve this. The most powerful of these devices also provide facilities for transforming the image co-ordinates, e.g. to provide apparent rotation or perspective projection of the image. Brightness can be varied to achieve a 'depth' effect or to highlight certain features, and other facilities are also available, such as flashing images, or in the case of plotters various line-widths and pen colours.

'Raster' devices such as electrostatic plotters and raster-scan displays on the other hand operate on the television scanning principle and images are generated as a set of picture points. In the more sophisticated of these displays a picture store is provided which relieves the main computer of the need to store the image once transmitted. This also enables part or all of the picture to be 'undrawn', a useful facility when modifications to the picture are needed. Straight-lines drawn on a raster device at an angle to the horizontal do not appear straight due to the regular spacing between picture points. A compromise has therefore to be achieved between picture quality and cost (high-resolution costs more). A typical TV picture has approximately 400×600 picture points, whereas for high quality 100 picture points or more to the inch are necessary.

4.5.4.2 Satisfactory speed comparisons are difficult to provide in the case of these devices as the effective information transfer rate depends to some extent on the content of the image displayed rather than the time taken to draw it. For electronic vector displays the drawing rate is high (typically 4000 cm/sec), whereas for mechanical devices slewing rates are limited by inertia and power available to speeds of the order of 100 cm/sec or below. Raster-scan displays of course operate at television speeds, but the number of new picture points altered per second is limited by the computer's ability to calculate their position (max. 0,1M picture points per second). Such ranges may be put in perspective by noting that the band-width necessary to display a moving television picture (with colour and shading) exceeds 10 megabits/second (1.2 million 8-bit characters/second). The rapid production of half-tone images is thus still beyond the capacity of most general-purpose computers. However, high quality images of this kind have been produced on an experimental basis using substantial amounts of computer time (6).

4.5.4.3 For line-images such as graphs and line-drawings, raster-scan displays are beginning to supplant earlier types of device, due to their lower cost. For high speed, high resolution applications where the image has to be changed dynamically, the vector refresh display is culate their position (max. 0,1M picture points per used, and this is the method employed in Lloyd's Register for the finite-element model work described above. For applications which do not require frequent updating of the image, storage tube devices are available. These have the advantage that the image is stored on the screen itself rather than in a computer store, so there is effectively no limit on the complexity of images that may be displayed other than the long drawing-time needed.

4.5.5 Devices for input of graphical images to a computer are much less well developed, since the process of graphical input implies interpretation of the meaning of the image.

Until now this part of the process has had to be accomplished by a human operator, using devices such as

Digitisers (See plate No. 6)
Light-pens
Cross-hair cursors

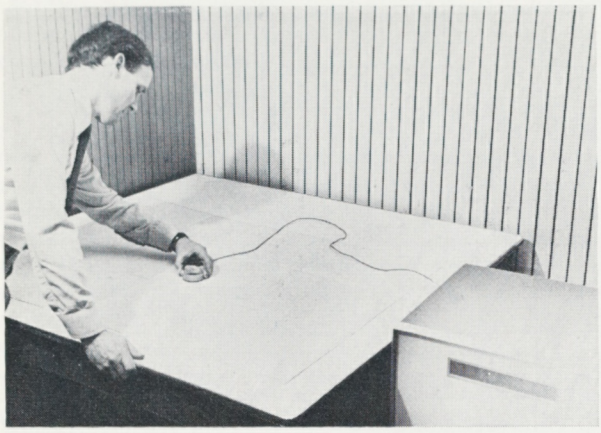


PLATE No. 6

Digitiser in use

4.5.5.1 Digitisers consist of a table, to which the drawing to be digitised is attached, and a means of indicating to the computer the point whose co-ordinates are to be digitised. The user positions a sensor head (typically containing a magnetic, acoustical or pressure-sensitive transducer) over the required point on the drawing using cross-hairs or graticules, and presses a button, whereupon the co-ordinates are recorded in the computer on a machine readable medium. The rate at which this can be done is very low, typically 5 points/minute on average. and eyestrain and fatigue are obvious factors causing errors and inaccuracies. There is thus a high premium on software which can correctly infer intermediate points on the curves on a drawing from as little digitised data as possible, and Lloyd's Register has therefore invested in some sophisticated curve-fitting software for this purpose.

4.5.5.2 The remaining devices in this category, light-pens and cross-hair cursors, enable a point on a graphic display image to be identified. The light-pen is a hand-held device which sends a signal to the terminal displaying the picture whenever the display beam passes it. Extensive use of light-pens is fatiguing but they are quite rapid in use and allow easy selection from entries in a displayed 'menu' of commands or selection of points on a drawing. Alternatively a cross-hair cursor can be displayed and moved about the screen at the user's wish, via 'thumb-wheels', 'tracker balls', 'cursor keys' or 'joysticks' attached to the terminal. All of these devices are employed in various ways within Lloyd's Register for appropriate purposes. The drawbacks of all these devices are similar to those of digitising equipment.

4.5.5.3 The band-width available for graphical input is thus very small. However, Lloyd's Register receives much of its working data in the form of plans and lay-outs. Before this data can be acted on by a computer it must be transcribed in some way. Using conventional digitising equipment this is a tedious and expensive task.

4.5.5.4 In co-operation with the Imperial College of Science and Technology, Lloyd's Register is therefore investigating the possibility of connecting a television camera or other type of scanning device to a computer to digitise drawings, initially under human guidance, but eventually it is hoped largely automatically. A prototype system of this kind has been constructed, intended for hull shape take off for tonnage measurement, and has already produced promising results (Fig. 6). Work on both the software and the hardware for this system is proceeding and it is envisaged that the device, which is of comparatively low cost, will find a large number of applications. Particular applications already foreseen include photogrammetry of damaged structures and input of diagrammatic information to the computer.

In the longer term, such methods may be combined with character recognition to permit entire drawings to be read. At that point one of the major obstacles to the automatic searching of archives for relevant engineering data will have been removed. It is too soon to predict the eventual information band-width of such devices but the prototype described above already offers the promise of a factor of 100 improvement over existing methods (7).

4.6 Electronic Communication

This has been dealt with in its various forms in previous sections of this paper. The ease with which machines can communicate with each other is limited by the requirements of the physical interconnection and the 'protocol' or data organisation sent over the connection. Despite vested interests, many of which have acted to restrict the possibilities for connection of one device to another, progress is being made towards de facto and official standards which permit connection of devices of different manufacture, for example:

The RS232 (asynchronous) interface for low-speed devices
The IBM 2780 protocol for Remote Job Entry devices,
The IBM 370 channel interface for high speed device attachment,
The HDLC protocol (Digital Equipment Corporation) for network communication,
The X25 (protocol) and X21 (physical) interface standards for international packet switching networks.

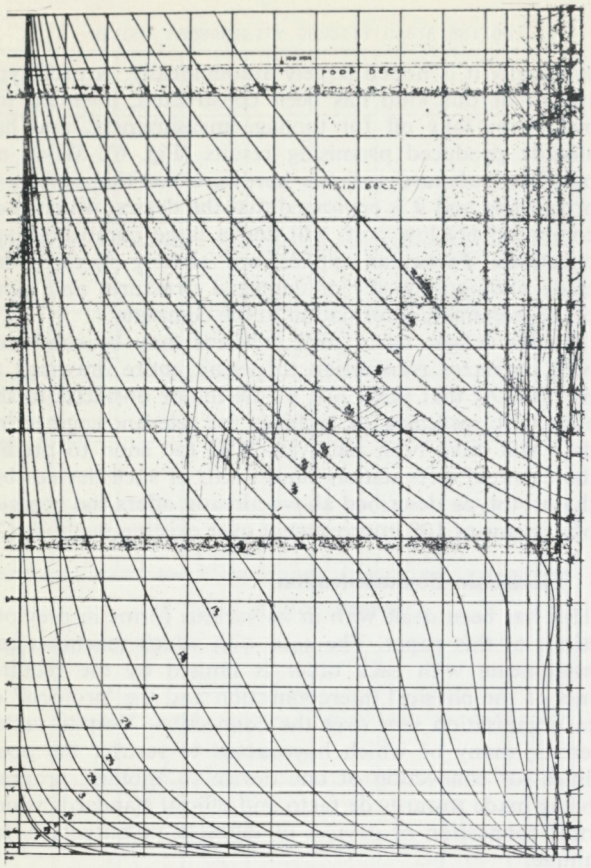
4.7 Other Forms of Communication with Computers

The only other form of communication with computers in widespread use is speech. Devices for translating computer data into the spoken word are now becoming quite sophisticated and in the near future are likely to be put to use in many new ways. An example is the Texas Instruments 'Speak and Spell' machine which shows what may be achieved in this field in the foreseeable future with 'micro-chip' technology. Voice recognition, too, is in its infancy but useful results have been reported. Perhaps the most obvious application for this will be in the field of dictation, although this is some years away. Both audio input and output are by nature likely to remain relatively low-bandwith channels of communication.

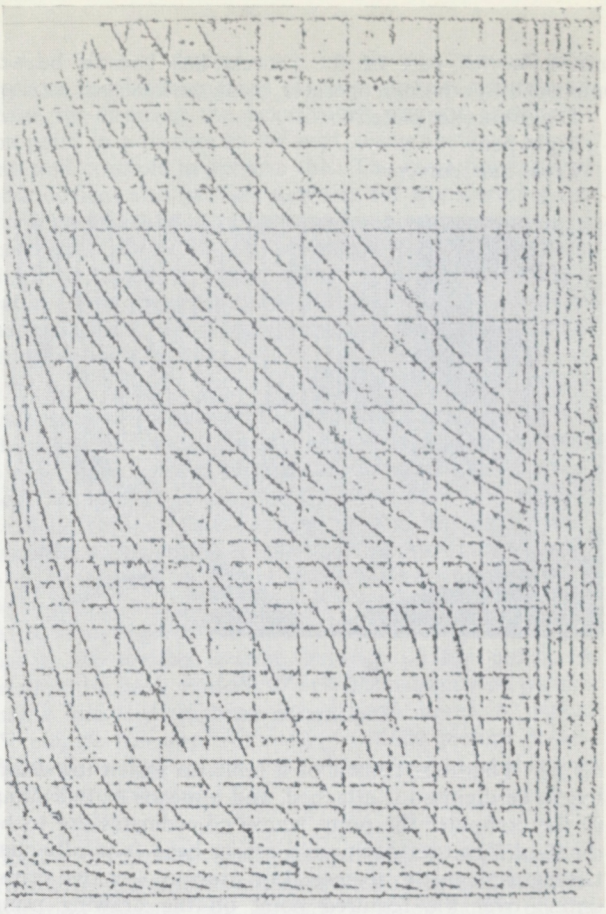
5. LANGUAGES FOR COMMUNICATION WITH COMPUTERS

5.1 Previous sections of this paper have dealt with the physical aspects of communicating with computers. In particular, it was shown that communication towards a computer is inherently slower than communication in the other direction. A means has therefore to be found to enable concise instructions to generate complex actions in a precise and controllable manner.

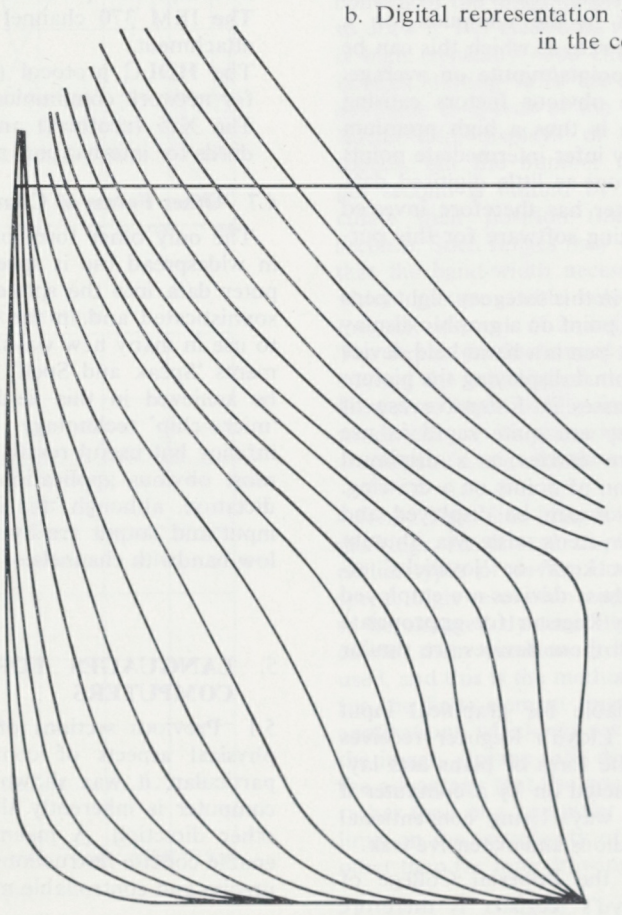
5.2 All communication with computers involves the use of some kind of 'language'. The greater the 'compression ratio' between the complexity of the instructions passed



a. The original engineering drawing (note imperfections)



b. Digital representation with no filtering as initially held in the computer's store



c. Computer plot of data extracted from b. by the computer under human control

FIG. 6

The use of video input techniques to digitise an engineering drawing

to a computer and its actions, the higher the level of the language is said to be. Computing languages are evolving slowly towards higher levels as ways are found to separate out the various logical components of the activities which users wish to carry out. This separation process has been found to be desirable not only so that users can understand the concepts readily but so that the instructions covering one aspect of the function can be specified independently of the others.

5.3 The first, 'low-level' computer languages dealt very much with the minutiae of computing such as the various error conditions that can arise when handling files, and decisions as to which storage locations and arithmetic registers were to be used were left to the user. Into this category fall 'machine' and 'Assembler' languages. Because such languages allow direct control over the way in which the computer handles a computation, they are still used for tasks where optimisation of speed or storage is important.

5.4 The first generation of 'high-level' languages, e.g. FORTRAN, ALGOL 60 and COBOL, allowed the user to concentrate largely on instructions relating to his problem rather than their layout in the store of the machine, and to define variables which are manipulated in much the same way as in mathematical expressions. However, the range of operations allowed in those languages was in general limited to simple operations to be performed one at a time, e.g.:

```
    A=B+C                          (FORTRAN)
or  ADD B TO C GIVING A.           (COBOL)
or  a:=b+c;                        (ALGOL 60)
```

Even at this level, the size and complexity of these languages became quite large and in the early 1970's a further language appeared, called BASIC because it was intended to be simple and easy to learn, having fewer facilities.

```
    LET A=B+C                      (BASIC)
```

in original BASIC has now almost universally been shortened to A=B+C as in FORTRAN.

5.5 FORTRAN and later BASIC found favour amongst engineers because these languages have a quasi-mathematical format and offer a good compromise between terseness and incomprehensibility on the one hand and long-windedness on the other. COBOL became widespread in business use because of its self-documenting qualities (similar to English) but is perhaps unnecessarily long-winded.

5.6 Due largely to the inertia effect generated by the need to maintain large numbers of programs written in these languages in the 1960's and 1970's, their development has continued, and they remain today the main avenue of communication with computers. ALGOL 60 was a casualty except in academic circles, largely because being intended to be machine-independent, its specification did not include effective verbs for input and output. A further language, PL1, available on IBM computers, was an attempt to combine the good features of all these languages, but did not raise the level of the programming task.

5.7 Since the late 1960's attempts have been made to extend the power of computing languages still further, The languages described above all incorporated effective means of segmenting a program, but with the exception of ALGOL 60 and PL1, did not provide a means of ensuring that these segments were logically distinct. The range of verbs included was also not exhaustive, for example none of these languages originally included a SORT verb. Some of these deficiences remain, while others have gradually been overcome, either within the frame of the original languages, or in later languages such as ALGOL 68, PASCAL, APL and FORTRAN 77, which have not yet gained such widespread acceptance.

5.8 A feature of all the languages described so far with the exception of APL is that they are essentially 'computer oriented' rather than 'application oriented' that is, they require the user to think in terms suited to the computer rather than the other way round. The ease with which computers can be used in the future will depend heavily on the extent to which the computer can react to instructions in the user's terminology. An example of such 'application oriented' languages is GIS (8), a package written in Assembler for information retrieval, widely used in LR for retrieving and tabulating information from large files of data. The SIFT package, written in APL and developed at LR (9), fulfils a similar role, e.g.

```
GET THOSEWITH GRT GREATERTHAN 50000
```

would retrieve records for ships over 50 000 Gross Registered Tons from a ship file. When considering programming languages for future use, it is important to choose a programming language with which it is possible to construct such 'user oriented' languages. This should if possible be machine-independent or 'portable' so that one does not lose the facility if the computing equipment is changed. Implementation of high performance tools of this kind in the earlier high-level languages COBOL and FORTRAN is, unfortunately, difficult as the range of commands available in these languages is not sufficiently powerful.

5.9 To run a program in a conventional high-level language like FORTRAN or COBOL normally requires that it first be compiled or translated into a lower-level language which can be interpreted efficiently by the machine. Recently, the cost/performance improvements in computers have enabled the designers of such languages to be more prodigal of computing resources and this for the first time permits the direct interpretation of computer languages with the flexibility this provides to stop, inspect and alter a program while it is running. Languages such as APL and BASIC were implemented with this ability in mind, while older languages in general do not allow this degree of flexibility. For the purpose of design checks, such flexibility may be dangerous, but for the other purposes it is a decided advantage.

5.10 The other feature of recent languages that should be mentioned is the incorporation of vector and array processing, e.g. in APL the statement:

```
    A←B+C
```

may be used to add two numbers together, to add two strings of numbers together (vectors) or to add two arrays with any number of dimensions together. Other operations permit other operations in matrix algebra, including inversion, to be specified very concisely. Extensions to both BASIC and FORTRAN for the same purpose have been made recently available for some machines, e.g.:

```
    MAT A=B+C
```

in HP9845 BASIC.

5.11 Unfortunately, the day of the single, portable, all-suitable computer language is not yet with us, nor are all existing languages available on any machine. Until then communication with computers will continue to require careful judgement. On the correct choice of computer language often depends not only the short-term success of a computer system, but its competitiveness in the future.

6. DIRECT/INDIRECT USE OF COMPUTERS

6.1 Many of the developments and devices discussed earlier in this paper have been directed towards making the computer more accessible to users, particularly engineers. At the same time, because of wider availability and application of computers and more relevant training in schools and universities, more engineers are now familiar with the techniques and concepts of computing than before. The advent of micro-computers is already causing a rapid change in the way control systems and other logical functions in engineering products are constructed. The logic is being implemented, not in hardware as before, but in software, where it can be changed and improved more quickly and cheaply. It is therefore to be expected that engineers will increasingly use computers in their daily work, of whatever engineering discipline this may be, and whatever their role.

However, just as electronic engineering has become a specialist discipline in electrical engineering because of the specialist knowledge required, so software engineering (i.e. systems analysis and programming) has become a separate discipline, with its own expertise, and the engineer must know when to take advantage of this.

6.2 If a mechanical engineer doing research were to devote his time to designing and building an oscilloscope it would be regarded as a misapplication of his time and a waste of money. Instead he uses an oscilloscope designed and maintained by electronic engineers, and if he encounters a problem he seeks their advice. On the other hand he must know enough about oscilloscopes to be able to operate them effectively and know when best to use them. Likewise, the designer of oscilloscopes must have a range of applications in mind if he is to achieve a useful end product.

6.3 In a similar way the best can only be obtained from computers if the skills and knowledge of the user engineer and the computing specialist are both used to the full. To use his own time effectively the engineer must often delegate significant aspects of the task of constructing and operating computer systems, and seek advice where appropriate. Those providing computer services must be competent to understand the aims of engineers who wish to use computers and provide appropriate basic software tools and hardware facilities for them to use. As in business systems the best results are obtained if engineering systems are discussed, designed and implemented as a co-operative activity between the user and the computing specialist. In that way both parties gain in knowledge, and a result is achieved which incorporates the knowledge of both, often quicker than if either tried to complete the task on his own.

6.4 Where computer systems or equipment are complex and individual engineers use them only infrequently, rather than the engineer using the equipment 'hands on', it may be more effective to train a specialist to extract or format the data or operate the equipment with the engineer 'looking over his shoulder'. A particular example of this in LR is the interactive graphics system, on which specialist operators develop great rapidity, and thus speed communication between the engineer and the computer.

7. ADDITIONAL FACTORS INVOLVED IN CHOICE OF EQUIPMENT

7.1 The earlier sections of this paper have illustrated the enormous variety of devices which have been developed in an attempt to enable men and computers to interact effectively. The pace of development shows no sign of slackening and is in danger of outstripping the capacity of industry to market and effectively use devices before they are outdated. In such a situation it must be recognised that despite competitive pressures there comes a point where the cost of change exceeds its benefit, and it is necessary to continue to use outdated equipment for a time until the benefits of change again outweigh the cost. The rate at which industries and individual companies market and adopt new devices and methods is thus likely to be dominated in the foreseeable future not by technological change but by economic inertia.

7.2 Another factor acting to reduce the rate of change is the necessity to preserve compatibility between new and old devices on the one hand, and between new computers and old programs on the other. The investment in software by most organisations now comfortably exceeds their investment in hardware. Accordingly there is a very strong argument for evolutionary rather than revolutionary changes in the computing field, with new devices able to interface to older computers, new computers able to run older programming languages and devices, and so on.

7.3 It would be pleasant to report that such evolution was leading rapidly towards a situation where the present widespread incompatibility between one computing device and the next and between different dialects of the same computing language would disappear, and the user would be free to choose the device and method most appropriate to his problem. Unfortunately, commercial pressures often act in the reverse direction and prompt suppliers to prevent interfacing of their equipment to that of other manufacturers. Thus despite the variety of devices available, great care is needed to select equipment and software which not only provides the facilities needed but will remain usable and competitive with new approaches and devices for more than a short time. Such a choice often involves careful timing, as a premature choice may severely reduce the lifetime of the software developed for the application.

The direction chosen by the manufacturers for the evolution of their equipment may also inhibit the user from moving in the direction he requires or even from communicating with the computer in the way he wishes, and there comes a point where revolutionary change, for example the adoption of a new type of computer using different languages and terminal devices, may be the only solution. Similar considerations apply to the choice and timing of changes to new items of basic software, e.g. operating systems, file-handling and terminal-handling software.

7.4 A further major consideration in the choice of equipment for communication with computers is reliability. The need for reliability varies considerably with the application, but broadly speaking the more rapid the response of the system is to be, the greater the reliability required. The availability of a computer as seen by the user depends not only on the physical integrity of the equipment, including the computer itself, its storage devices, peripheral equipment and communication links, but also the correctness of the software, the load on the computer and its components (which may cause unacceptable delays to occur at terminal devices if capacity is insufficient), correct operation of the computer and archival storage procedures, and environmental failures such as air conditioning and power supply.

7.5 Techniques for achieving high availability are now fairly well understood and at least one range of computers (TANDEM) has been designed with non-stop operation in mind. This is achieved by duplication of hardware and

software and rapid communication between computers to ensure that if a failure occurs in any component the process can continue elsewhere in the system. Although provision of this degree of availability is expensive it is becoming increasingly desirable not only in sensitive applications such as dynamic positioning systems for drill rigs and support vessels but also increasingly in office applications where the day-to-day work of many individuals may depend upon the availability of the computer. Unfortunately design for continued availability despite equipment software failure is still the exception rather than the rule though this may be expected to change over the next decade. Meanwhile worthwhile improvements in hardware reliability are occurring as the result of 'micro-chip' technology.

7.6 In the short term, the most practical step that can be taken to improve availability is to ensure that back-up equipment is readily available. This means that as far as possible new equipment selected should be compatible with existing equipment, that terminal equipment and software should be chosen to permit many types of application to be run from any terminal, and that the variety of computer terminal types, computing languages and basic software should be kept to a minimum consistent with achieving the required objective. In Lloyd's Register for this reason the introduction of computers, languages and operating systems which would discourage such flexibility has been avoided as far as possible, despite the fact that on occasions this has gone against individual preferences.

8. FUTURE DEVELOPMENTS AND THE NEEDS OF ENGINEERS IN LLOYD'S REGISTER

8. The level of communication required between engineers and computers depends heavily on the type of work in which the engineer is engaged. Within Lloyd's Register the application of computers by technical departments already varies from the extensive use of pocket calculators for ad hoc calculations to the use of extremely sophisticated input and output devices and large amounts of computing time for applications such as structural and thermal analysis. Not surprisingly, it is at the lower end of this range of power and complexity that the needs of engineers can be said to have been best met in the shortest time. At the next level up, the desk-top computer, the situation is also rapidly improving, with the recent introduction of graphical devices at relatively low cost for the first time.

8.2 A high proportion of the work of engineers involves interpreting and generating graphical images, as this is a more compact form of representation of physical data than text or tabulations. With the advent of these new lower-cost devices graphical communication with computers is therefore expected to assume a primary role as the power of computers at all levels increases and storage costs continue to fall.

8.3 Despite the advances already made and on the immediate horizon, there is however no prospect in view that the computing needs of engineers will be fully satisfied. Many types of application now stretch the capacity of even the largest computers to the full, and one has no difficulty in envisaging applications well beyond this scale. For example, detailed calculation of the fluid flow past an offshore platform in various conditions of wind and tide is at present well beyond the capacity of all but the largest computers and would be totally uneconomical in present conditions, however desirable. Likewise even the static analysis of structures at present often relies on approximations which are necessary solely because of limitations on computing capacity, speed and cost.

8.4 Studies of the dynamics of large structures, non-linear analyses, simulation, unsteady thermal flow, design optimisation, real-time data handling are other areas in which increased computer power would allow the engineer in Lloyd's Register to provide a better service. The advances expected in the next decade, in particular array processors and processor networks, will substantially reduce, if not eliminate, these barriers to better modelling of the physical world, and at the same time permit easier handling of the large amounts of data involved.

8.5 Storage and searching of large amounts of technical data will also become easier and more cost-effective than at present. The real barrier to such activities may well turn out to be the difficulty of collecting accurate and relevant data, but here too the micro-computer will be of considerable help in obtaining and filtering data obtained from experiments, field measurements and inspection.

8.6 During the same period the use of computers for word and text processing will increase rapidly and this is expected to ease significantly the work of the engineer in producing and amending his reports.

8.7 Progress in LR will continue on all these fronts in the next few years. Considerable advances have recently been made in providing a unified system for interactive access to the central computing complex. The interfacing of desk-top machines and intelligent terminals to this complex will shortly provide technical staff with access to a network providing a wide range of computing capacities and facilities for data storage. The complex will then grow by the addition of different processor types, storage and terminals as may be appropriate in the state of future technology. At the same time it will be connected to an ever wider variety of media for communication, which will in due course also allow Surveyors overseas to access the same facilities as those in Headquarters and to transmit, edit and receive data. Within Headquarters it will be necessary to provide a flexible and powerful means of inter-communication for data traffic so that terminals may be moved without rewiring the building to convenient locations as required. Portable terminals and the digital equivalent of pocket dictation and playback machines may also prove useful to the Surveyor in the field.

8.8 In conclusion, the last few years have seen astonishing advances in the range and performance of all types of computing equipment. As a result the variety of methods of communication with computers is now very wide. Many of these are already in use and available in Lloyd's Register. Nevertheless considerable further progress is required in techniques and languages for communication, in particular in the direction from humans to computers, before the computer can become an effortless extension of the mind of the engineer. This goal will be actively pursued.

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Discussion

on the paper

ON COMMUNICATING WITH COMPUTERS

by

Messrs. C. J. J. Beart, J. D. Short
and G. K. Henderson

Paper No. 3. Session 1979-80

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Discussion on the Paper by
Messrs. C. J. J. Beart, J. D. Short and G. K. Henderson
ON COMMUNICATING WITH COMPUTERS

CONTRIBUTIONS

From Dr. D. Sepahy:

I would like to congratulate the Authors and welcome their interesting and informative paper on computers in L.R.

When I first saw the announcement of a paper on communication with computers, subjects like network theory and switching techniques, optic fibres, communication satellites and the structure of interactive language came into my mind. To my surprise the paper is on the practical and down to earth subject of computers within L.R., discussed in simple language and I am sure that it will be a good introduction and usefully fill the gap in such information for technical and non-technical staff, especially for newcomers to L.R.

Almost a decade ago, in an era which saw the emergence of the giant tanker and the L.N.G. carrier, complex structural analysis had to be carried out. At that time we had an IBM 360/40 computer with only the capacity and performance of the present desk top computer; therefore we had to use outside machines. I well remember the days when I carried cards and printed output to and from the IBM Bureau and worried every time I submitted a job to the computer because I knew we were paying at an expensive rate for every minute of its time. Nevertheless I enjoyed every minute of it since I had the opportunity of obtaining first hand experience. Time progressed and when the IBM 370/158 was introduced to L.R. my mode of communication with the computer was somewhat changed, except that I had to spend the occasional weekend at L.R. or would receive telephone calls from operators at midnight saying "Your job has stopped" and in most cases I had to get to the office. Since then the workload has dramatically reduced and at the same time the capacity and performance of computers have also increased. Nevertheless colleagues still occasionally spend weekends at the office to see a job through. Cards and printout are still with us and their volume has increased. I have resisted accommodating bulky input and output since I see it as a passing phase. I would like to ask the Authors whether I can still be optimistic or do I have to face reality, and learn to live with cards and printed output, and order more racks to accommodate them?

The paper has clearly explained the different types of computer and classified them according to technical specifications, capacity and performance and no doubt this should clear up misunderstandings in the definition of different computers. I would like to see the cost range for each type of computer and I wonder if the authors can supply this information.

I am concerned and alarmed to see so many different types of computers and different types of computer language, particularly some of those languages which are highly specialized; these are sometimes said to be unnatural to engineers and mathematicians (1). I am sure that in some cases users have unknowingly fallen into computer manufacturers' traps in this respect. I would like to ask the Authors if we are going through a period of uncertainty or whether variety adds to the spice of life—but at what cost? I appreciate the geographical and present technological limitations in communication but I am not sure about the advisability of having several computers in the same building. I consider communication within any organization to be a top priority therefore it should be brought about even at the expense of other needs.

The word 'intelligent' has been used by the Authors in an esoteric way; I am sure it is not used literally, referring to the ability to produce different solutions to a specific problem. Therefore further clarification is required, especially when one hears terms like 'future intelligent machines'.

The subject of Section 6 possibly requires a separate paper of its own. I agree partially with the view expressed in this section and especially support the idea of software engineers provided the minimum technical qualifications are fulfilled.

I am bewildered by the phrase 'pitfall of approximation' used by the Authors and possibly some explanation is required. The engineer can produce a result for a problem at a cost of £5 where others do the same thing for £100: The reason is that he makes a lot of engineering approximations.

Is it possible for the Authors to give some figures for improving the productivity of programming if interactive FORTRAN programming facilities are used; I have come across figures of 30% to 100%?

With reference to Section 8.3, I would like to quote a statement made by Prof. L. Landweber in his opening paper at an international conference on numerical ship hydrodynamics in 1977. "Where previously, as in ship wave theory, mathematics had out-stripped computational capacity, after the computer became available the situation reversed" (2). Good approximation is not a limitation; it is a cost effective solution to any problem.

I would like to make the following suggestions which could equip every individual to cope with the expected rapid change and advances in computers and computing:

1. The formation of computer user groups to ensure direct involvement and commitment on the part of the user.
2. A computer newsletter which will eventually be communicated via V.D.U.s.
3. Positive incentive in the use of computers. Computer use should be treated truly as an overhead like the use of telephones, typewriters and other office equipment.
4. Positive incentives to use the computer in a simple way.
5. The communicating mode of the computer should have priority over the parochial mode.
6. A continuous programme of computer training and education; the use of computers to assist learning, as suggested in the previous L.R.T.A. paper on training (3).
7. A clear policy should be laid out for long term R & D in engineering and the required software. This should be pursued in either centralized or well co-ordinated and cohesive activities, even if only in a modest way.

References:

1. P. S. Abrams. What is wrong with APL. Scientific Sharing Corporation, Bethesda. MD20014, U.S.A.
2. L. Landweber. Ship Hydrodynamics—Then and Now. 2nd International Conference on Numerical Ship Hydrodynamics. University of California, September 1967.
3. R. S. Cornwell. The Staff Training Program, 1979. Lloyd's Register Technical Association, Paper No. 2, Session 1979-80.

From Mr. N. Sims:

There are many facilities within L.R. of which many potential users are ignorant, and the Authors' paper will be of great benefit to many colleagues in bringing these to their notice and explaining their potential and limitations, together with those we may expect to encounter in the near future.

The major point I should like to make concerns the almost total lack of training in the computing field available to the technical staff. A basic knowledge of the mainframe system could make a considerable difference to the many users; it is potentially dangerous to use anything if one does not know how it functions, and an awareness of the aims and operation of one's JCL could in many instances forestall costly errors.

In the execution of a large-scale structural analysis, much labour is involved in calculating, preparing and checking the mass of loading and geometry input required. The wide variety of problems encountered in these jobs makes it virtually impossible to produce universally applicable pre-processors; the currently available software is of strictly limited use, and any projected developments must, to be of any use, be undertaken in close consultation with the users—this being a policy not much in evidence in the past. The user is thus forced to resort to hand calculators and self-written desk-top programs, involving the transfer of large quantities of data by hand, a process which is slow, tedious and very prone to error. Batch-job editing of data is subject to the same criticisms. Instruction of users in the writing and running of small "one-off" FORTRAN programs and in the techniques of storage and transfer of large amounts of data directly via computer media, combined with training in direct, terminal-based data editing would pay dividends in making the process vastly quicker and more reliable than the present system. I feel sure that this approach would benefit all users of programs involving large quantities of input data.

If I may raise one further point, on a more basic level: that of hand calculators. A great many of the calculations required by the technical staff of the Society could be readily handled on some of the more advanced programmable calculators now available. Limited use of these would surely pay off, if only in reducing the load on desk-top machines. When the time comes for the replacement of current calculators, great attention should be paid to the wants of the users in selecting appropriate machines, taking the utmost advantage of the rapid developments in this field.

From Mr. O. Hopkin:

I think that many of us are familiar with the term computer without being fully aware of the specific techniques and concepts embodied. The Authors are to be congratulated on providing a review of the computer facilities available at H.Q. and an insight into their functioning.

Whilst a knowledge of the sophistication of devices, both in terms of hardware and software, is necessary for efficient operation, I think I can safely say that the majority of users are only interested in achieving a successful computer run. The provision of R. J. E.'s (Data 100) has aided the user by simplifying job input. The C.R.J.E. terminals working on APLSV, with direct access to the computer for data handling prior to submission, are promoted as being of even greater help to the user. Is it not time that the input or JCL procedure was removed from the users responsibility? I believe a system, TONE3, exists which will perform this function yet contains many similarities with the APLSV system mounted at LR.

In the case of more sophisticated analyses or those requiring larger amounts of computing time and greater use of input/output devices, the concern is with solving the problem in the most efficient manner, thereby extracting the most from the system. This requires some knowledge of the exact functioning of the system. In this area, there is a requirement for a better understanding of the interface between the various groups of specialists, be they engineers, programmers or system analysts, in terms of mutual education and communication.

A specific example can be seen on the interactive-graphics side, where two independent systems are being run and developed. Also, the situation arises where development is executed by one group, but supporting software, is not abreast of developments; this being the responsibility of another group who have not kept up to date. Is this always to be the case with software development?

To the future, it seems likely that there will be considerable advances made in computer aided design techniques, leading to fully computerised designs. It begs the question of approval procedure to be adopted and the class position if such a design is submitted for approval.

With the advent of larger capacity and faster hardware becoming available at H.Q., will it be fully occupied with in-house work, or is the door open for acceptance of bureau-type work, which can be backed by the well known LR service of experience and expertise?

AUTHORS' REPLY

Messrs. Sepahy, Sims and Hopkin have raised a number of points of considerable interest, which we will do our best to answer in the order they were raised.

To Dr. Sepahy:

It has been evident for a number of years that the cost of paper and cards would rise faster than the cost of providing access to a computer through terminals. The cost of storage of bulky printouts is also increasing as time goes on and the world's stock of trees is fast being depleted. From almost every point of view, ecological as well as practical, it is desirable that the use of paper and cards should soon be superseded by the use of terminals and magnetic storage. Besides providing a cost advantage these allow the user to search and summarize data more effectively and quickly. However despite these advantages it is to be expected that paper will remain the preferred medium for the forseeable future for a number of reasons, amongst which we would mention portability, ease of copying and ease of annotation. Within a controlled and orderly environment such as L.R. Headquarters, there is the prospect of using terminals in the near future to avoid large amounts of print-out except where these are required by a client, and of extending the use of magnetic media and microfiche, already used for bulk archival storage, to further application areas. However, the true advent of a 'paperless' society will have to await further advances in the development of truly portable, cordless terminals with facilities for copying and annotation.

The longest word length on a commercially available

mainframe computer is 60 bits (CDC 6600/7600). Typical cost ranges for various types of computer and storage (1978 figures) are shown in Tables A and B.

The reasons for the proliferation of computer languages are many, but two main causes stand out; the limitations of existing methods of communication with computers and the dictates of commercial competition. Advances in this field like many others are made by a process of proliferation of ideas followed by consolidation, and both take place, simultaneously in a fast-developing industry. During the 1970s the limitations of the languages such as FORTRAN and COBOL designed in the late 1950s began to become expensive rather than just inconvenient, and the search has now begun in earnest for better ways of communicating algorithms. We share Dr. Sepahy's concern at the situation. L.R.'s policy is to endeavour to keep the number of computer languages in use within L.R. to a minimum while taking advantage as far as possible of the advances which are being made. Many of the ideas embodied in recent languages, for example BASIC (simplicity), APL (interpretation and array-handling) and PASCAL (type- and value-checking) have real practical (commercial) advantages, as does the use of one of the older standard languages. However the choice is often circumscribed by the fact that the equipment manufacturers offer only one language on a particular device, (e.g. BASIC on Hewlett-Packard desk-top computers).

The co-ordination of many different computers does present a problem and if not carefully organized, a substantial expense. The fashionable arguments for decentralization have already lost ground to some extent in the face of the difficulties of co-ordinating the maintenance of distributed databases and software. The simplest way to resolve these difficulties, where sharing of data and/or facilities is necessary, is to centralize, while giving proper attention to reliability of the central facilities, communication with users and the provision of adequate capacity to ensure reasonable response times. Advances now being made in the theory and practice of distributed databases will in due course undoubtedly allow greater decentralization to be achieved where necessary without loss of control. The optimum layout of computing networks of the future is likely to be dictated largely by the extent to which communication of facts between one user and another is necessary or desirable.

The word 'intelligent' is used throughout the paper to mean 'having the capacity to discriminate', i.e. in the case of computer terminals, having some local computing power. The extent of this power varies from device to device and may in the future even increase to the point where 'intelligence' in the human sense can be simulated by machine.

The introduction of errors due to approximations made in the course of a calculation is a phenomenon perhaps more readily understood when using a slide-rule than a computer; nevertheless, when using a computer a constant watch has to be maintained that rounding errors in the representation of numbers in the computer do not accumulate to the extent that all precision is lost. This can usually (but not always) be achieved by correct selection of the method and sequence of the computation. Sometimes however the characteristics of the problem itself permit no accurate solution (see for example Ref. 1). It is therefore essential for engineers who use computers to be aware of the effect of the approximations they are making and of the characteristics of their problem in this respect. The search is on for computing languages and hardware which will automatically warn the user of inaccuracies in the result if a computation continues.

Figures commonly quoted for the improvement in programming speed when interactive terminals are used are normally in the range quoted by Dr. Sepahy. However a distinction has to be drawn between interactive debugging and interactive programming. The tendency to program while sitting at a terminal (or at a desk-top computer) has to be firmly resisted if such gains are to be achieved. Rapidity of response is no substitute for careful thought, and can easily preclude it. Improvements in the elapsed time taken for implementation of simple tasks well in excess of a factor of ten have routinely been experienced using interpretative languages, due in part to the ability with these languages to make program corrections 'on the fly', i.e. while the program is being executed.

The recommendations listed at the conclusion of Dr. Sepahy's contribution are most helpful and will be carefully considered. It is perhaps worth noting that a start has already been made in most of the directions he has proposed, as well as in planning improved training for users in computer techniques as requested by Mr. Sims.

To Mr. Sims:

As noted by Mr. Sims, the pace of development in hand-held calculators is very high. A determined attempt is already made by the Computer Operations Department at H.Q. to keep abreast of these developments and recommend the most appropriate alternative. Those who have a requirement for a calculator should contact that Department.

To Mr. Hopkin:

Mr. Hopkin refers to the need for users to specify IBM Job Control Language instructions when jobs are submitted to the computer. Facilities like APLSV and the TSO* time-sharing system soon to be implemented in L.R. do permit simple jobs to be submitted without the user needing to specify JCL. However JCL remains, for good or ill, the primary means of controlling the facilities of IBM mainframe computers at the detailed level. Jobs requiring non-standard access to the facilities of the computer will continue to require some form of JCL to be submitted, even though this can be 'clothed' in some more acceptable form of language by means of a preprocessor such as TONE3, or a CLIST or APL function. Improved methods of communication with the computer, including the communication of control functions is indeed the main reason for the introduction of APLSV and TSO into L.R.'s computing systems.

Until the process of computer and operating system design proceeds further and permits control of detailed matters in higher-level languages, it will remain necessary for users who need to exercise detailed control over system functions to be familiar with system control languages such as JCL and to liaise closely with the specialists who support these systems. Effective communication of users' needs is the only way to avoid the kind of mis-match between applications and software support referred to by Mr. Hopkin.

The divergence between the versions of the PDP-11 interactive graphics system for Offshore and Hull Structures Departments was necessary owing to space limitations within the machines at the time the Offshore version was developed. In practice it is sometimes cheaper to permit divergence of this kind than to attempt to force users into accepting a compromise which performs neither function properly. Convergence of the software again at a future date when rewriting is necessary for other reasons would of course be desirable and is not ruled out.

L.R. is limited by its constitution as to the type of work that can be undertaken for Clients using facilities such as the computer. However it has been felt for some time that many of our facilities and much of our software could be

used more directly in the interests of Clients without contravening these restrictions. The facilities which can be offered to Clients and the basis on which they can be offered are described in references 2 and 3.

**Authors' Note:* Since this discussion took place it has been decided to implement TSO rather than the VSPC system.

References:

1. Sensitivity of Matrix Eigenvalues, G. J. Davies and C. B. Moler, Int. Jnl. Num. Meth. in Eng., Vol. 12, 1367-1373.
2. Brochure 'Computer Services of Lloyd's Register': Lloyd's Register of Shipping, June 1979.
3. Lloyd's Register Computer Services Computer Program and Availability List, Oct. 1979.

DEVICE		CPU CYCLE TIME (microseconds)	MAIN STORAGE MAX. (K. Bytes)	PURCHASE PRICE (£)	COST/BYTE (p)	CPP PRODUCT*
DESK TOP COMPUTERS:						
HEWLETT PACKARD	9820	8.0	13	6120	47	377
,, ,,	9825	0.8	24	5900	25	20
,, ,,	9830	8.0	32	7720	24	193
,, ,,	9845	0.8	64	10600	17	13
VENTEK DATAPOINT	2200	1.6	16	7500	47	75
,, ,,	5500	0.8	48	15500	32	26
IBM	5110	0.530	64	10100	16	8
MINI COMPUTERS:						
KIENZLE	6100.8	1.0	100	14400	14	14
DEC PDP	11/34	1.0	248	23000	9	9
,, ,,	11/60	0.6	248	29500	12	7
,, ,,	11/70	0.410	4000	310000	8	3
MAINFRAME						
IBM	370/138-1	0.275	1000	241344	24	7
,,	370/158-1	0.115	6000	1440700	24	3
,,	370/168-1	0.080	8000	2322709	29	2

N.B. *C.P.P. PRODUCT = $\frac{\text{Purchase Price (p)}}{\text{Main storage (K. Bytes)}}$ × CPU cycle time (microseconds)

TABLE A. CENTRAL PROCESSORS — POWER AND COST (as at April '78)

DEVICE		CAPACITY (CHARS)	ACCESS TIME (MSEC.)	MAX. TRANSFER RATE (KCH/SEC)	PURCHASE PRICE (£)	CHARS/p	CHARS/SEC/£
Data Cassette	(e.g. HP9865)	48000			1260	0.38	
Data Cartridge	(e.g. HP9877)	250000	6000	0.2750	1430	1.7	1.9
Diskette	(e.g. HP9885)	468500	267	23.0	2000	2.34	11.5
Disk Cartridge	(e.g. P.D.P. RK05)	2400000	70	1440	3600	6.7	400
Disk	(e.g. IBM 3330)	100000000	30	806	22000	45.0	36
Disk	(e.g IBM 3350)	317500000	25	1198	20000	158.0	60

TABLE B. DISK STORAGE — CAPACITY, TRANSFER RATE AND COST (as at April '78)

ERRATA

To Paper No. 3. Session 1979-80

On Communicating With Computers

1. **Fig. 2**

   a) Penultimate column should read:

   2

   10–4000

   ,,

   ,,

   ,,

   10^5

   –

   ?

   b) Last column should have an additional pair of ditto marks opposite 'mainframe computer'

2. Para 2.5.2 Heading should read:
   Minicomputers (and . . .

3. Para 4.5.4.3. The line

   culate their position . . . points per

   should not be present (it has been inserted in error from the previous para)

4. Para 5.7 top line of p.15

   deficiencies

5. Para 5.10 line 7

   'Operations' should be 'operators'

6. Plate No. 5 Caption 'ICON in use' should be deleted.

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3
SEP

Lloyd's Register Technical Association

ASSESSMENT OF STRENGTH REQUIREMENTS FOR SHIPS OPERATING WITHIN RESTRICTED SERVICE LIMITS

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Senior Ship Surveyor
LLOYD'S REGISTER OF SHIPPING

D. W. Robinson

Paper No. 4. Session 1979-80

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Brian E. Prince, C. Eng.
Senior Ship Surveyor
LLOYD'S REGISTER OF SHIPPING

ASSESSMENT OF STRENGTH REQUIREMENTS FOR SHIPS OPERATING WITHIN RESTRICTED SERVICE LIMITS

By D. W. ROBINSON

1. INTRODUCTION

1.1 General

The majority of ships classed with the Society are of the unrestricted sea-going type, with minimum strength requirements laid down by the Rules. These requirements, evolved in the past, over a considerable number of decades, are based mainly on 'what went before' and in-service experience.

Significant changes to the strength rules for sea-going ships have been brought about in the last twenty years by relatively rapid changes to ship proportions and/or form. For such changes to be reflected in the Rules, 'new' techniques had to be used to assess the wave induced loads, as the then current technique of poising the ship on a L/20 or 1.1 $\sqrt{L}$ static wave was no longer relevant. Supertankers and fast dry cargo vessels were two examples where existing techniques would have produced over design and under design respectively. The environment had not changed, although, one could argue that a different trading route affected the tankers, what had changed, were the relative wave induced loads brought about by the different ship proportions and forms.

The 'new' techniques referred to above, have given us, in the last decade, the ability to verify theoretically the relative environmental loads for almost any design parameter variation.

This paper deals with the use of such theoretical techniques for assessing wave induced loads and hence strength requirements specifically for restricted service vessels, based on environmental information representative of the area of operation.

Although the main emphasis of this paper will, of necessity, be concerned with establishing the 'restricted' environment in which a ship is to operate, the techniques described are applicable to any environment. It should be noted at the outset that while services designated 'sheltered water' and 'short voyages' in the present Rules (1) are a form of restricted service, they are generalisations still requiring full modulus. Therefore, by 'restricted service', the author means a different definable environment to that assumed for 'unrestricted service', implying, also, a different modulus.

1.2 Need for Individual Assessment

Although alternative strength standards do exist for restricted environment operation, for example, for service in the Great Lakes (2), changes in trading patterns and ship types take place so rapidly that existing rules or modifications to them, are not the best means of establishing minimum strength requirements due to lack of feedback. It is therefore logical to match, if possible, strength to conditions by incorporating the same implied factor of safety as that for unrestricted vessels. This would seem obvious at first, producing probably a lighter vessel or one with a distribution of material to match the particular environment in which the ship operates.

The main disadvantage of designing with a particular trading pattern in mind, is that the ship may be unsuitable if that trading pattern or route changes appreciably or disappears altogether. In this case it would be extremely difficult and costly to modify the vessel for say, unrestricted service.

The use of a calculation method to assess individual strength requirements for restricted service is implied in several places of the Society's Rules (1). In particular, the following service restriction notations indicate this need:— "Protected Waters Service, Extended Protected Waters Service, Specified Coastal Service, Specified Route Service and Specified Operating Area Service".

1.3 Definition of Restricted Service

What is the meaning of "restricted service" in the context of this paper? It means operation within a limited trading area where environmental conditions are different from those likely in unrestricted service, and, probably less severe. To be able to assess the environment within such limited areas, their boundaries must be defined by geographical limits. These can consist of specified stretches of coast coupled with a maximum distance from the shore or areas enclosed by coastlines (Lakes) or enclosed by coastlines and straight lines between specified points. Definitions such as "harbour service" or "river estuary service" do not, in the author's opinion give an adequate indication of the type of service unless the specific area and its limits are properly identified.

2. BASIS OF ASSESSMENT

2.1 General

In the majority of restricted service cases, longitudinal strength is the most important requirement to satisfy. Its assessment usually requires the determination of still-water and 'low frequency' wave-induced bending components. The still water bending component is derived in a well established deterministic manner (3) common to all services and need not be considered further. The low frequency wave-induced bending component, however, is derived on a probability basis using techniques developed over the last decade and it is the description of these techniques and their application which will be discussed in this paper. The assessment of local strength requirements based on the wave-induced loads and motions will be touched upon briefly.

Although the probabilistic method to determine the wave-induced loads has become a relatively 'standard' procedure and does, in fact, form the basis of the Society's current Rule requirements, it can only be used in a qualitative or comparative way. This means that a reference or base service is also required. This is in no way unusual, as most advances or extensions in ship design rely heavily on past experience, comparisons with similar situations, and extrapolations of existing knowledge.

The use of a base service with recognised and satisfactory strength requirements means that, provided the wave conditions and hence wave-induced loads are obtained for the base service and the proposed restricted service, there is no need to derive absolute values for the two areas. However, to ensure that the relative comparisons and conclusions drawn are correct, the wave conditions and loads need to be as accurate and reliable as possible, and this is the philosophy adopted for all investigations. This concept is particularly important in fatigue life analysis, as the value of the calculated life depends very much on the

magnitude of the applied load spectrum. Therefore, provided the relative magnitude between the base and proposed service is correct and the loads realistic, the relative increase or decrease in fatigue life should also be realistic, all other factors being equal.

2.2 Choice of Base Service

Ideally, a base service with environmental characteristics close to the intended service would provide the best choice, with the proviso of course, that these environmental conditions can be established. This latter requirement is particularly important and usually dictates the base service to be used.

Although wave conditions throughout the world have been observed and often reported on for centuries, surprisingly little is known in usable scientific terms of vast areas of the oceans, let alone the restricted areas being considered. This position is changing slowly, but at the present time, there are only a few areas for which the necessary environmental data and associated strength requirements are available, thereby limiting the choice for a base service. The most important and probably the most useful base service area, from the Society's point of view, is the North Atlantic. Here, the environmental conditions are well documented and in a form and quantity suitable for analysis, and have been used to establish the current strength requirements for ships on unrestricted service.

Other areas can be used as base services, but usually in a limited sense. The Great Lakes provide an example where the associated strength standard and, therefore, experience is linked to a particular breed of ships, namely, 'Lakers'.

2.3 Estimation of Wave-induced Loads

2.3.1 General Outline

A generalised approach to establish design loads for unrestricted or restricted service is shown in Fig. 1. Three paths to establish the important environmental data are shown and although other methods exist, these three represent the most likely ways at present to produce the wave scatter diagram required for analysis.

The total theoretical model, which is described more fully in Section 3, consists of five main elements, namely:

(a) establishing wave height and period data representative of long-term conditions.

(b) fitting statistical distributions to the sea state data.

(c) deriving dynamic responses to regular sinusodal waves.

(d) deriving short-term response variances using either actual or formulated spectra.

(e) Obtaining short or long-term response estimates to be used for design.

The final link to convert the theoretical model, with all its assumptions and approximations, into realistic service loads is correlation with full-scale measurements or related experience.

2.3.2 Assumptions

The first basic assumption used when specifying methods for the assessment of local and longitudinal strength, is that the whole analysis of the environment in which the vessel operates, the resulting loads and subsequent life can be described statistically (4), (5), (6). This in turn implies that relevant environmental data are available and in a form suitable for use in the analysis. The suitability of the available wave data, is assessed by comparative adequacy checks using standards obtained from experience within the Society. At first sight, measured data would seem the ideal choice, but, as they tend to be of limited duration due to high costs, the total recording period must be checked as being representative of the long-term. Generally, the longer the recording period of measurements or observations, the more likely it is to be representative of long-term conditions, with the additional proviso that the recording locations are also representative of the 'total restricted area' being considered.

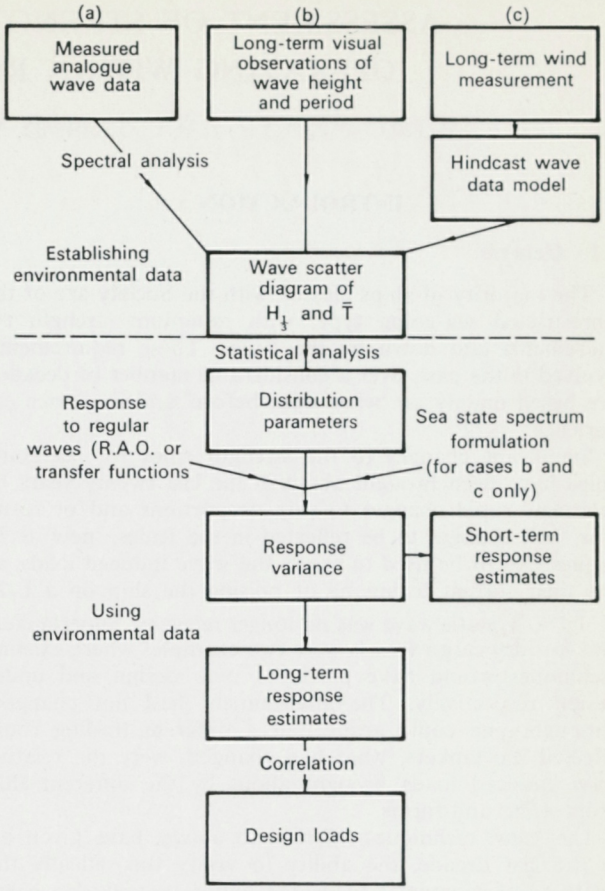


FIG. 1.

Outline Flow Diagram to Establish Design Loads.

Other important assumptions, in the context of the applied techniques used in the assessment of strength requirements are as follows:—

(a) that the hull girder is considered to act as a rigid beam.

(b) that Bernoulli's hypothesis is accepted, namely, plane sections remain plane during bending.

(c) that the superposition principle applies when calculating wave-induced responses. This implies that responses are assumed linear with wave height.

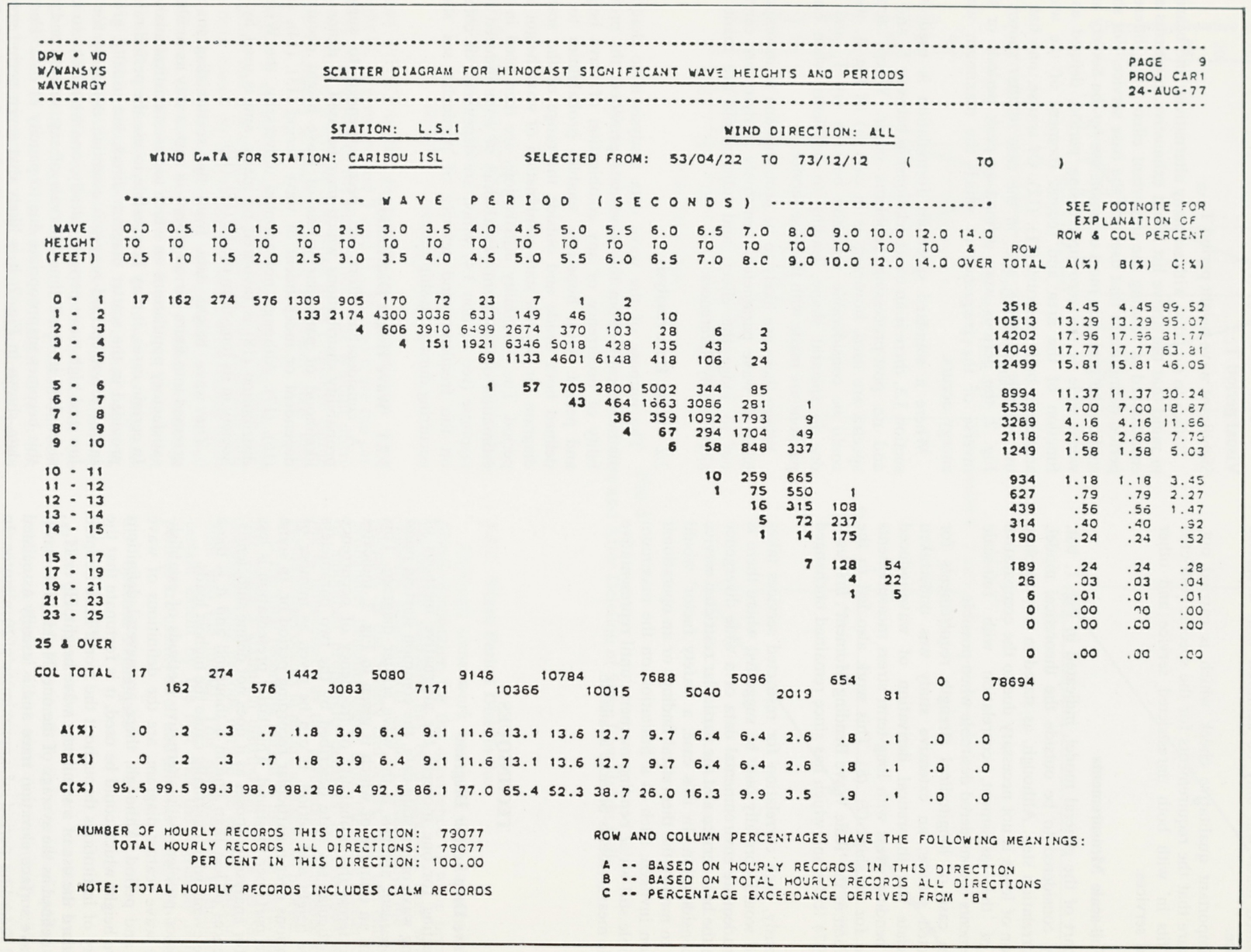
(d) that hull girder excitation forces can be derived from small motions theory.

(e) that motions do not deform the wave profile during its progression along the hull.

2.4 Validation Procedures

2.4.1 Calculation Checks

A considerable amount of validation is carried out on the various components of the theoretical model during the course of the calculations, taking the form of comparative checks with standards established previously from the base service.



DPW * WD
W/WANSYS
WAVENRGY

SCATTER DIAGRAM FOR HINDCAST SIGNIFICANT WAVE HEIGHTS AND PERIODS

PAGE 9
PROJ CAR1
24-AUG-77

STATION: L.S.1 WIND DIRECTION: ALL

WIND DATA FOR STATION: CARIBOU ISL SELECTED FROM: 53/04/22 TO 73/12/12 (TO)

WAVE HEIGHT (FEET)	WAVE PERIOD (SECONDS) 0.0 TO 0.5	0.5 TO 1.0	1.0 TO 1.5	1.5 TO 2.0	2.0 TO 2.5	2.5 TO 3.0	3.0 TO 3.5	3.5 TO 4.0	4.0 TO 4.5	4.5 TO 5.0	5.0 TO 5.5	5.5 TO 6.0	6.0 TO 6.5	6.5 TO 7.0	7.0 TO 7.0	8.0 TO 9.0	9.0 TO 10.0	10.0 TO 12.0	12.0 TO 14.0	14.0 & OVER	ROW TOTAL	SEE FOOTNOTE FOR EXPLANATION OF ROW & COL PERCENT A(%)	B(%)	C(%)
0 - 1	17	162	274	576	1309	905	170	72	23	7	1	2									3518	4.45	4.45	99.52
1 - 2					133	2174	4300	3036	633	149	46	30	10								10513	13.29	13.29	95.07
2 - 3						4	606	3910	6499	2674	370	103	28	6	2						14202	17.96	17.96	81.77
3 - 4							4	151	1921	6346	5018	428	135	43	3						14049	17.77	17.77	63.81
4 - 5									69	1133	4601	6148	418	106	24						12499	15.81	15.81	46.05
5 - 6									1	57	705	2800	5002	344	85						8994	11.37	11.37	30.24
6 - 7											43	464	1663	3086	281	1					5538	7.00	7.00	18.87
7 - 8												36	359	1092	1793	9					3289	4.16	4.16	11.86
8 - 9												4	67	294	1704	49					2118	2.68	2.68	7.70
9 - 10													6	58	848	337					1249	1.58	1.58	5.03
10 - 11														10	259	665					934	1.18	1.18	3.45
11 - 12														1	75	550	1				627	.79	.79	2.27
12 - 13															16	315	108				439	.56	.56	1.47
13 - 14															5	72	237				314	.40	.40	.92
14 - 15															1	14	175				190	.24	.24	.52
15 - 17																7	128	54			189	.24	.24	.28
17 - 19																	4	22			26	.03	.03	.04
19 - 21																	1	5			6	.01	.01	.01
21 - 23																					0	.00	.00	.00
23 - 25																					0	.00	.00	.00
25 & OVER																					0	.00	.00	.00
COL TOTAL	17	162	274	576	1442	3083	5080	7171	9146	10366	10784	10015	7688	5040	5096	2019	654	91	0	0	78694			
A(%)	.0	.2	.3	.7	1.8	3.9	6.4	9.1	11.6	13.1	13.6	12.7	9.7	6.4	6.4	2.6	.8	.1	.0	.0				
B(%)	.0	.2	.3	.7	1.8	3.9	6.4	9.1	11.6	13.1	13.6	12.7	9.7	6.4	6.4	2.6	.8	.1	.0	.0				
C(%)	99.5	99.5	99.3	98.9	98.2	96.4	92.5	86.1	77.0	65.4	52.3	38.7	26.0	16.3	9.9	3.5	.9	.1	.0	.0				

NUMBER OF HOURLY RECORDS THIS DIRECTION: 79077
TOTAL HOURLY RECORDS ALL DIRECTIONS: 79077
PER CENT IN THIS DIRECTION: 100.00

NOTE: TOTAL HOURLY RECORDS INCLUDES CALM RECORDS

ROW AND COLUMN PERCENTAGES HAVE THE FOLLOWING MEANINGS:

A -- BASED ON HOURLY RECORDS IN THIS DIRECTION
B -- BASED ON TOTAL HOURLY RECORDS ALL DIRECTIONS
C -- PERCENTAGE EXCEEDANCE DERIVED FROM "B"

FIG 2.

Typical Wave Scatter Diagram.

Some parts of the model will be identical to both the base service and the restricted service, for instance, the assessment of responses to regular waves, and thus will not need validating. However, final evaluation of the calculated or correlated loads will only be achieved with in-service experience.

One important qualitative check which is carried out, is to ensure that the requirements for the specific restricted service 'fits in' with both unrestricted service and other restricted services.

2.4.2 Full-scale Measurements

One part of the general model, indicated in Fig. 1, but, normally considered to be outside the theoretical model, is the correlation step. Although, as stated in 2.1, absolute evaluation of loads is not necessary due to the comparative nature of the assessment, correlation with full-scale measurements is considered desirable when possible.

In the case of longitudinal strength requirements for unrestricted service, an extensive study was undertaken to correlate the theoretical derivation of wave-induced vertical bending stress with long-term stress measurements available for 26 ships (7), (8). This work also led to the formulation of the 'Rule Wave Bending Moment', first used in the 1974 Rules and which has since remained unchanged (1).

Obviously, such correlation for restricted services takes time and would normally only be suggested where there is either inadequate environmental data or a wide divergence between the base service and the particular restricted service under consideration. In this case, a 'safety factor' would be used to modify the theoretical findings or an operational restriction invoked, such as a limitation on the maximum permissible still water bending moment, until representative full scale measurements became available.

3. TECHNIQUES

3.1 Wave Data Scatter Diagram

Neglecting for one moment the alternative methods of obtaining wave or sea state data, the common starting point for subsequent analysis is the wave scatter diagram. This diagram, an example of which is given in Fig. 2, indicates in basic terms the probability or frequency of occurrence of a particular sea state described by the two parameters of wave height and period. It can be given as number of observations over a particular recording period or, in some cases, in parts per thousand. This latter presentation is less useful for analysis purposes as it does not define sufficiently, occurrences of less than one in a thousand and it is these extreme events which normally cause the highest loads.

A major problem with alternative methods of establishing the wave scatter diagram, are the definitions of wave height and period. Although, there are several definitions of wave height which could be used, it is fortunate that the majority of institutions throughout the world have adopted as standard the use of a significant wave height, H_s or $H_{1/3}$, This is defined as the average of the one third highest waves in a wave surface elevation trace and is usually associated with a recording period of approximately 20 minutes. In the case of visual wave height observations, most are considered close enough to $H_{1/3}$ to be taken as its equivalent (9) (10). For wave periods, however, there are several definitions used as 'standards' by different organisations, examples being:—

Significant or average wave period T_s or T_o

Average energy period T_e

Characteristic or zero up-crossing period $\overline{T}$ or T_z

Peak spectrum period T_p

Visual period T_v

Significant wave height period $T_{H1/3}$

Suffice to say, that with so many alternatives, and bearing in mind that the above list is not exhaustive, problems are encountered in relating the important effect of a different period definition to that used for the base service. For ship studies, the period in most common use by the Society and world wide is the zero up-crossing period, defined as a function of the area and second moment of the wave amplitude half spectrum (11), (12). Of course, one has to use what is available, and, in the case of that shown in Fig. 2, the periods were defined as peak periods or the inverse of the frequency at which the maximum wave energy occurs.

Where a standard spectrum formulation is used, see section 3.3, there is an exact relationship between T_p and T_z and no post-processing problems occur. Where actual spectra are used, however, as in case (a) of Fig. 1, there could be considerable variation between say T_p and T_z due to spectral shape, leading to problems when comparisons are made with the base service.

Where there are likely to be problems due to incompatibility of wave parameters, sensitivity analyses are carried out to judge the effect, and adjustments are made to alleviate any differences.

3.2 Wave Data Analysis

The purpose of the wave data analysis is to describe mathematically, from the wave data provided, the probability of occurrence of any combination of wave height and period. This, hopefully, enables probabilities to be defined both inside and outside the range of the scatter diagram for any sea state combination of wave height and period. The probability distributions are then used in the estimation of long-term probabilities of wave induced ship response (see Section 3.4) which are dependent, of course, on the frequency and severity of particular sea states occurring during the ship's life.

3.2.1 Wave Height Distribution

A considerable effort has been expended to suggest probability distributions which may be used to define the likelihood of particular values of wave height occurring dependent or independent of wave period (13), (14), (15), (16), (17). Although not adopted universally, the Weibull distribution (18) is favoured by many, and is used by the Society in its long-term model (17), (19).

The wave height data from the scatter diagram are grouped into finite period groups in such a way as to obtain satisfactory populations on which to base statistical analysis. In certain cases, it may be possible to use the period ranges provided in the scatter diagram direct, but usually, grouping of several period ranges is essential, especially for the low and high wave periods. Ideally, one would like to consider data in small time intervals of say, one second, but this becomes inappropriate due to paucity of data. For the data shown in Fig. 2, it is likely that seven period groups would be used; less than 4 seconds, $4<5$, $5<6$, $6<7$, $7<8$, $8<9$ and over 9 seconds.

The height data within each period group are then analysed using either a desk top (20) or main frame computer program (21), which, using at least squares procedure,

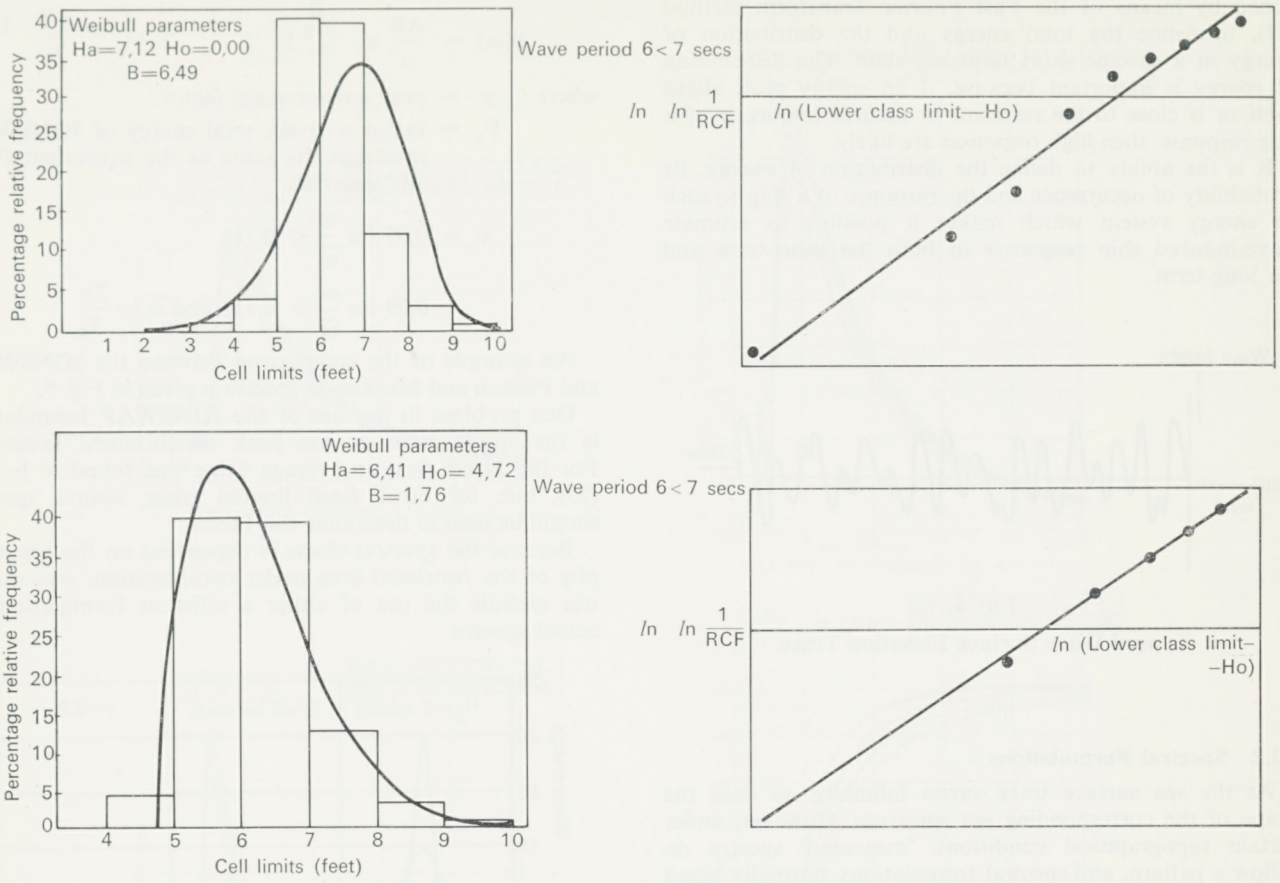


FIG 3.

Weibull Analysis of Wave Height Data Before and After Deletion of Some Low Height Cells.

provides the 'best fit' of the data to a Weibull distribution defined by the function:—

$$P(H/T) = e^{-\left\{\frac{H - H_o}{H_a - H_o}\right\}^b}$$

where P(H/T) is the probability of exceeding a wave height H, of given period T and H_a, H_o and b are the calculated parameters of the distribution. The Weibull distribution plots as a straight line when /n /n 1/relative cumulative frequency is plotted against /n (lower class limit $-H_o$).

Figure 3 shows the plotted output from the desk top program, and it is evident from the top two diagrams that the data shown by the histogram and corresponding spots are not, in this particular case, a very good fit to the Weibull distribution. However, neglecting a very small percentage of low height data below Cell 4 to 5, produces an excellent Weibull fit to the data as shown in the lower two diagrams of Fig. 3. This procedure is justified, in the author's opinion, to obtain a reliable fit to the extreme events, enabling realistic probabilities to be assigned to events outside the range of the scatter diagram. It should be pointed out that this deletion of some of the low wave height data is not always necessary, but, is very useful in the longer period ranges to filter out underlying swell waves from the important wind waves.

The analysis is carried out for all the grouped period ranges enabling the probability of any wave height for a given period to be defined.

3.2.2 Wave Period Distribution

Although some work has been done to specify a statistical distribution for the occurrence of wave periods, no reasonable standard has been suggested that will cover different geographical areas. Consequently, the approach adopted by the Society and others, is to use either actual probability densities direct from the wave scatter diagram or 'smoothed' probability densities. In most cases, smoothing is unnecessary as the percentage occurrence of finite period ranges occurs in nature as a smooth process.

If the total recording period is low, one disadvantage of not fitting a statistical distribution to the periods, is that extremely long periods outside the scatter diagram are not built into the model. This disadvantage is nullified to a certain extent by the fact that the extremely long wave periods are usually swell and are, therefore, of low height.

3.3 Spectral Techniques

3.3.1 General

The description of a short term sea state by the two parameters of $H_{1/3}$ and T_z is a gross simplification of reality. A typical short term (approximately 20 minutes) wave surface elevation trace, an example of which is given in Fig. 4, would contain a large variation of both height and period.

If it is assumed that such an irregular wave trace is made up of a large number of infinitesimal sinusoidal waves of varying frequency, a wave energy spectrum may be ob-

tained by means of the Fast Fourier Transform method (22), to define the total energy and the distribution of energy in a specific short term sea state. The distribution of energy is important because, if an energy peak aligns itself or is close to the resonant or natural frequency of a ship response, then high responses are likely.

It is the ability to define the distribution of energy, its probability of occurrence and the response of a ship to such an energy system which makes it possible to estimate wave-induced ship responses in both the short-term and the long-term.

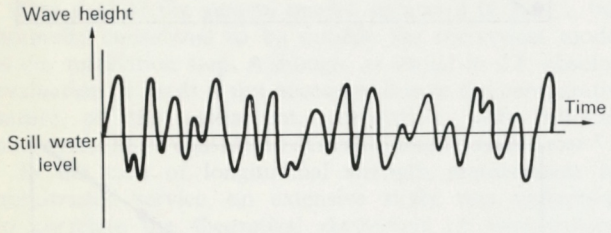


FIG 4.

Typical Wave Surface Elevation Trace.

3.3.2 Spectral Formulations

As the sea surface trace varies infinitely, so does the shape of the corresponding sea spectrum. However, under certain topographical conditions, 'measured' spectra do follow a pattern, and spectral formulations, normally based on the two parameters of height and period or their derivatives, are used in place of actual spectra. This is very convenient from the computing point of view, as the use of a general formula instead of a large number of 'actual' spectra, makes the mathematical model very simple to handle, provided, of course, one can standardize with one or two spectral formulations from the large number available.

3.3.3 Choice of Spectrum

There are two general classifications of spectral formulations which suit the Society's purpose and that of this paper, namely, those suitable for open oceans and those suitable for coastal or sheltered waters. For the open ocean or unrestricted service, the Society, along with many other organizations, has standardized on the use of the I.S.S.C. spectrum (23) which is derived from the original work of Pierson and Moskowitz (24), namely,

$$S(\omega) = \frac{AB}{\omega^5} e^{\frac{-B}{\omega^4}}$$

where $S(\omega)$ = spectral density (ordinate).

ω = circular frequency.

$A = 4m_w$ and m_w is the wave height variance.

$$B = 0.32\left(\frac{2\pi}{T_z}\right)^4$$

For coastal or restricted services, several coastal spectral formulations have been suggested, but, the Society favours the use of the JONSWAP(25) fetch dependent spectrum which is an adaption of the I.S.S.C. or Pierson and Moskowitz spectrum. It was formulated to fit a range of measured spectra in the North Sea, but is considered suitable for use in most fetch limited situations and is defined as follows:—

$$S(\omega) = \frac{AB}{\omega^5} e^{\frac{-B}{\omega^4}} F^{-1}{}_{\gamma} e^{\left(-\frac{1}{2\sigma^2}\left(1.406\frac{\omega}{\bar{\omega}}-1\right)^2\right)}$$

where γ = peak enhancement factor.

F_1 = factor to make total energy of JONSWAP spectrum the same as the equivalent P. & M. spectrum.

$$\sigma = 0.07 \text{ for } \frac{\omega}{\bar{\omega}} < 0.711$$

$$0.09 \text{ for } \frac{\omega}{\bar{\omega}} > 0.711 \text{ and } \bar{\omega} = \frac{2\pi}{T_z}$$

An example of the comparison between the JONSWAP and Pierson and Moskowitz spectra is given in Fig. 5.

One problem in the use of the JONSWAP formulation is the specification of the peak enhancement factor γ. For the North Sea, an average value was found to be 3.3 (25), but, for other fetch limited areas, sample spectra should be used to determine this factor.

Because the spectral shape is dependent on the topography of the restricted area under consideration, one would not exclude the use of either a different formulation or actual spectra.

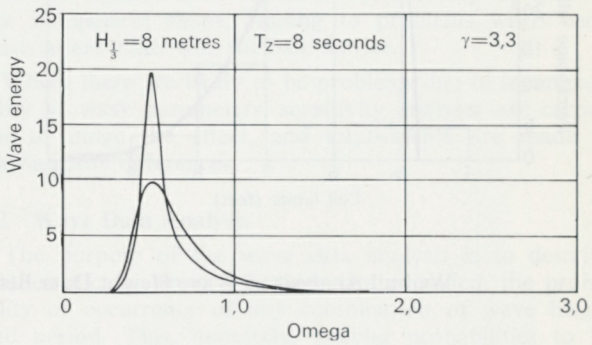


FIG 5.

Sea Spectrum Formulation Plots.

3.4 Short and Long-Term Response Prediction

3.4.1 General

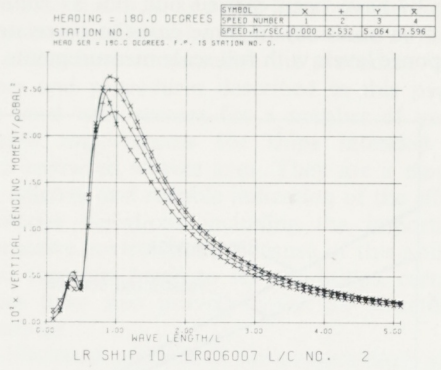
In the majority of cases, strength assessment for restricted or unrestricted services is based on estimated life-time or long-term responses. That is, the maximum response which occurs once in a ship's life-time of say 20 years.

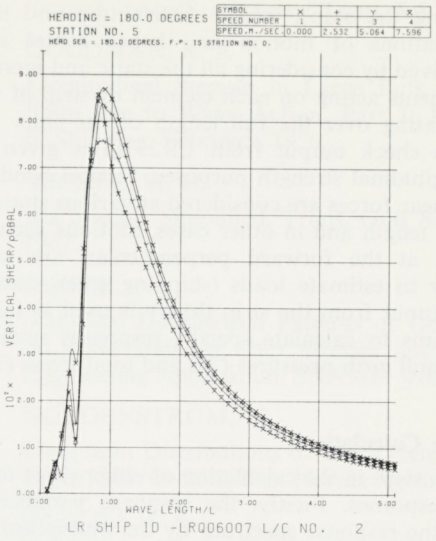
This is normally associated with a probability of 10^{-8} being the inverse of the approximate number of low frequency stress reversals that might occur in a period of 20 years. Where there is a possibility of a high frequency springing response being present, a lower probability is associated with the time period due to the larger number of stress reversals during the life-time.

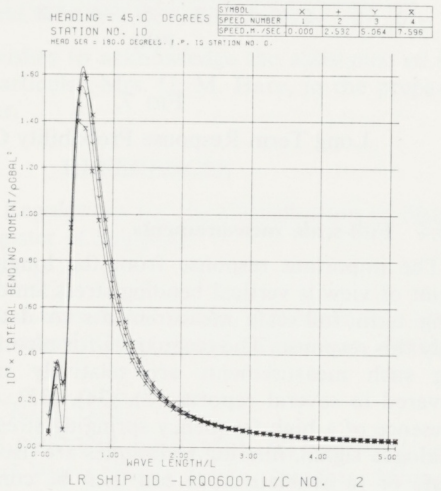
In isolated cases, longitudinal strength assessment may be based on short-term predictions of wave induced bending moments for design sea states. Also, short-term predictions of particular responses such as bow impact or slamming pressures are sometimes used in the strength assessment of local structure.

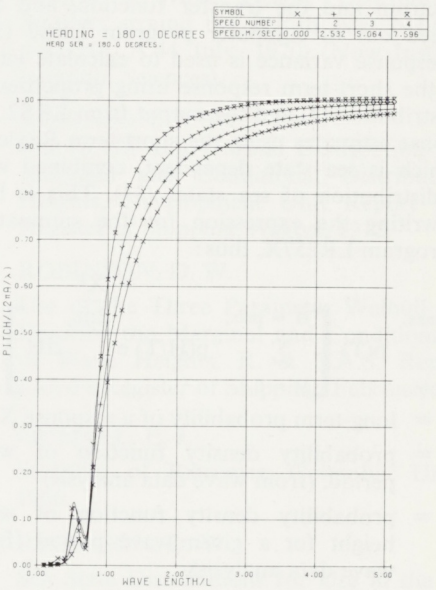
3.4.2 Response to Regular Waves

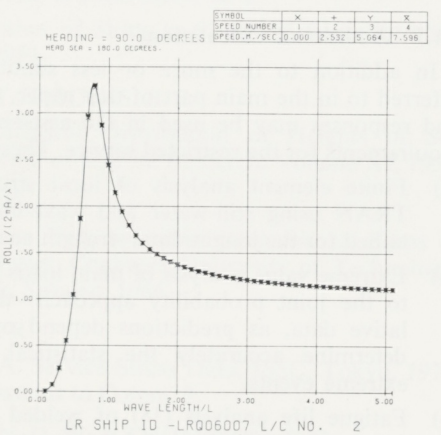
Ship responses to regular sinusoidal waves of varying length or frequency and unit wave amplitude are obtained in the majority of cases by the strip theory (26), (27) or, for unusual hull forms from model tests. These response data are called either Transfer Functions or Response











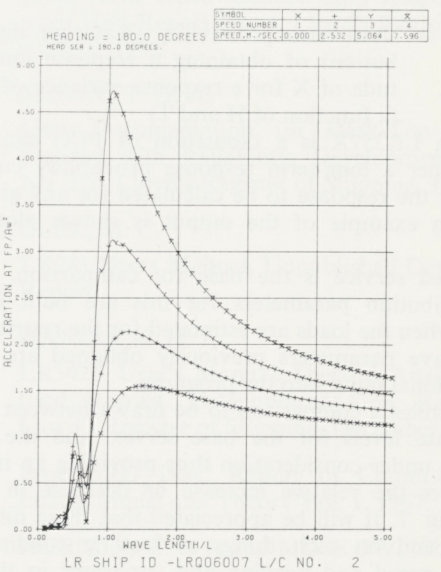


FIG 6.
Example of Strip Theory Output Check.

Amplitude Operators. It is the Society's practice to obtain these by the use of the strip theory program LR257Ø, the main input being the ship's weight distribution and hull form. The equations of motion and hence forces and moments are solved by considering all the static and inertial forces and moments acting on each element or strip of the ship and summating over the full length of the ship. An example of the check output from LR257Ø is given in Fig. 6. For longitudinal strength purposes, vertical bending moments and shear forces are considered at various stations along the ship's length and in other cases, motions such as relative motion at the forward perpendicular, are considered in order to estimate loads (shipping green water). Alternatively, output from the strip theory is used as input to other programs to calculate specific responses such as slamming (28), hull girth pressures (29) and total stress (30), (31).

3.4.3 Response Calculations

There are two steps in the calculation of either short-term or long-term responses. Firstly, the response variance is obtained from the response spectrum by the multiplication of the sea spectrum and the transfer function, and this process is carried out in computer program LRS2 (32). Secondly, the response variance is used to calculate either an estimate of the short-term response using properties of the Rayleigh distribution (5) and the output from LRS2, or, long-term response estimates using the short-term Rayleigh distribution, which is sea state dependent, combined with the long-term distribution of sea states (33). This is best illustrated by writing the expression for the summation carried out in program LR257X, thus:

$$P(X) = \sum_{T=\min.}^{T=\max.} p(T) \left[\sum_{H=0}^{H=\max.} p(H/T)\, e^{\frac{-X^2}{2m_o}} \Delta H \right] \Delta T$$

where $P(X)$ = long-term probability of a response X

$p(T)$ = probability density function of wave period. (from wave data analysis)

$p(H/T)$ = probability density function of wave height for a given wave period (from wave data analysis).

$e^{\frac{-X^2}{2m_o}}$ = short-term probability (Rayleigh distribution) of obtaining a response amplitude of X for a response variance of m_o (a function of H and T)

Output from LR257X is a tabulation of P(X) against X enabling either a long-term response probability curve to be drawn or the response to be calculated for any given probability. An example of the output is shown plotted in Fig. 7.

If unrestricted service is the base for camparison, the sea state distribution parameters for this are built into LR257X and when the loads are estimated for the restricted service, the wave parameters previously obtained are required as additional input into the program.

This step enables a comparison to be drawn between the relative response levels for the base service and the restricted service under consideration thus providing an indication of either the relative increase or decrease in responses, see Fig. 7. It will be appreciated that these differences will depend on such things as loading condition, response, ship speed and heading and variations in these parameters have to be considered to obtain a complete picture of the effect of going from the base service to the restricted service.

Where operational requirements lead to service in two distinct areas, the two areas are considered separately and the time spent in each is proportioned to obtain a revised response probability curve. In most instances, strength requirements can be assessed on the basis of these theoretical response levels, provided of course, that the various checks have been carried out, but as stated previously, it may be necessary in some cases to correlate the theoretical response levels with full scale measurements.

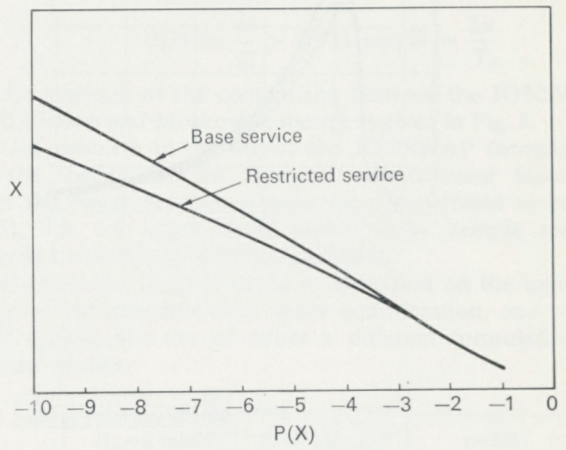


FIG 7.
Long Term Response Probability Curves.

3.4.4 Full-scale measurements

The important response from the longitudinal strength point of view is vertical bending stress amidships, and most long term full-scale measurements to date have covered only this response. The techniques for recording and analysing such measurements are relatively simple, and are covered in several reports, (7), (34), (35), (36). Where the presence of a high frequency springing stress is likely in the analogue signal, filtering techniques are used either to eliminate or to evaluate it. It can then be compared with the low frequency response as indicated above, or with a theoretical determination of the high frequency bending stress (37), if this response is of particular interest for the ship and area under consideration.

3.4.5 Additional Calculations

In addition to the more or less standard calculations referred to in the main part of this paper, other techniques and responses may be used in the assessment of strength requirements for the restricted service. These include:

(a) Finite element analysis of local structure by NASTRAN using still-water and wave-induced loads obtained for the longitudinal strength analysis.

(b) Extreme value analysis of main loads as an alternative to the joint probability approach—this needs superlative data, as predictions depend on the ability to determine accurately the statistical distribution of extreme events.

(c) Fatigue life analysis (38) of welded joints based on Miner's hypothesis and load spectra obtained from probability response curves for low and high frequency bending stresses.

(d) Estimation of slamming or bow impact pressures for the assessment of the fore end structure.

(e) Estimation of liquid cargo sloshing loads (39).

CONCLUSION

Prior to the use of computer aided load evaluation, strength assessment relied heavily on past experience. Where there was no experience, requirements for service in specified areas would be estimated to err on the conservative side. Whilst this was, and still is, a commendable maxim, it did not necessarily make economic sense as there was no way of telling how conservative the procedure was.

The techniques and procedures described in this paper have now been used with success for a number of years to assess strength requirements for ships intended to operate within a restricted service area. They are a means of providing an efficient and reliable indication of the effect of design parameter variations including the important effect of an alternative environment. Because of this ability to match relative response levels to sea conditions, certain of the techniques have also proved useful for structural damage investigations.

The methods discussed will not at the present time, give absolute values of wave induced responses. However, provided they are linked with either experience as a reference base, or full-scale measurements, they provide a sound basis for relative strength assessments to be carried out.

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Discussion

on

Mr. D. W. Robinson's Paper

ASSESSMENT OF STRENGTH REQUIREMENTS FOR SHIPS OPERATING WITHIN RESTRICTED SERVICE LIMITS

Paper No. 4 Session 1979-80

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Hon. Sec. S. M. Wehrle
71 Fenchurch Street, London, EC3M 4BS

Discussion on Mr. D. W. Robinson's Paper

ASSESSMENT OF STRENGTH REQUIREMENTS FOR SHIPS OPERATING WITHIN RESTRICTED SERVICE LIMITS

CONTRIBUTIONS

From Mr. B. Rapo:

On reading the Paper, one cannot avoid the impression that the title of the Paper contains a promise which has not fully materialized. It is quite possible that perhaps the title "Assessment of Wave Induced Loads" would be more in line with the content of the Paper than "Assessment of Strength Requirements".

In his conclusions, the Author refers to a number of practical applications using the technique for ships designed to operate in a restricted service area. If the Rule wave bending moment, M_W, is taken as a reference line after adjustment for service area, it would be of interest for the Author to comment on the numerical comparison of this value with that obtained using the method outlined in the Paper. Would such a comparison indicate a major deviation?

Since longitudinal strength considerations are only one aspect to be dealt with, could the Author provide some guidance on transverse strength and local strength aspects? Are they in any way affected by service restriction notations?

At the end it is suggested that the Author considers adding an Appendix to the Paper outlining the calculation procedure in a typical case.

In conclusion I would like to thank the Author for his paper.

From Mr. K. V. Taylor:

It has been said that the title of this Paper is somewhat misleading in that the Paper is concerned with loads and not strength. While this is largely true, it is generally more reliable to compare loadings than attempting to compare strengths.

What do we mean by strength? Do we mean a nominal design strength? Ultimate strength? Also, bear in mind that total failure can be caused by a fast running crack. Comparison of strength presents as many problems again to the designer as those of load prediction.

The Author rightly says that judgement of a design is not absolute but comparative and providing the appraisal is limited by the extent of the differences in loadings, these can be a reliable guide to strength capability. Obviously, as the paper indicates in Section 3.4.5, there is also a need for some local structure analysis and also fatigue life estimates but generally, for conventional ships, main hull girder design can be related on the basis of a vertical bending moment and a simple modulus calculation.

While the strip theory method has become highly respectable through the years and now provides quite accurate ship motion and load response predictions, long-term values depend on the mathematical definition of the long-term sea conditions and other assumptions as indicated in the Paper. Correlation with actual data is therefore essential in order that such models can be calibrated to provide realistic values. This procedure has been achieved particularly well for main hull stresses using measurements obtained from ships in service; References 7 and 34.

In connection with this, the Author has indicated that techniques for recording and analysis are relatively simple. While he suggests that it has been made to look simple, I would advocate that the recording of data is well established, the collection of data is generally simple, the processing of this information is tedious, but any meaningful analysis as discussed in reference 34 is far from simple. We only wish it was. I thank the Author for an interesting and thoughtful paper.

From Mr. T. Sullivan:

Not being conversant with the subject of wave induced loads in relation to minimum strength requirements for restricted service vessels, I was pleasantly surprised to find how informative the paper was in conjunction with the subsequent presentation and discussion and I congratulate Mr. Robinson.

I would like to ask the Author, whether, on a one-off basis due to economic considerations, the number and types of ship and actual time spent on a particular service by these ships together with the incidence of defects sustained would be of any material assistance in assessing the risks involved.

From Mr. D. T. Boltwood:

Initially I would like to thank the Author for presenting a most interesting paper.

My first point relates to the matter of ship response. An essential assumption adopted in the application of the strip theory is that the vessel's response in regular waves is proportional to wave height, i.e. linear response is assumed. For medium to large vessels of normal wall-side configuration, where motions are small, this assumption may well have some validity, but, for small vessels where forms may be irregular and motions large, it must be open to question. Since restricted service notations will, in general, apply to small vessels, I would appreciate the Author's comments on the applicability of the strip theory.

It would also be interesting to learn whether our present method of analysis can account for non-linear response in regular waves and non-linear response in irregular waves.

With regard to the practical application of the technique discussed in the Paper, I consider that it would be of great value to all Surveyors for the Author to include a detailed numerical example in the Discussion Paper clearly indicating each step of the calculation.

From Dr. A. Kamtekar:

In his most interesting paper, the Author has shown clearly the rigorous way of assessing the wave induced loads on a structure when it is to be designed for restricted service. Quite frequently, the Society has to advise Clients on possible relaxations of strength requirements when, for example, a ship has to travel a specified route at a specified time. Advice on such matters is given at present by comparing suitable wave heights in the areas through which the intended route passes with those in the North Atlantic. Could the Author say whether this simple approach can be justified on the basis of the method described in the Paper?

From Dr. F. A. Ramzan:

The Author has utilised strip theory for force evaluations. This is a first order calculation and does not include the second order hydrodynamical forces, due to low frequency components, dominant at small encounter frequencies. Would the Author please comment on whether he has considered such effects in his calculations and if not, how were these effects estimated to warrant no contribution.

AUTHOR'S REPLY

I would like to thank those colleagues who contributed to the discussion, as this allowed expansion of certain points and reference to some of the omissions.

To Mr. Rapo:

The title of most papers must present problems to Authors to convey, in relatively few words, a precis of the paper. However, it is my opinion that it is up to the reader to interpret what it means to him, and, if in this case it falls short of expectations, I apologise.

As stated in the Paper, restricted service means operation for all of the vessel's life in an area where the environment can be considered definably different from that expected in unrestricted operation. It should not be confused with the definitions of "short voyages" or "sheltered water service" of the Rules. These Rule designations are devices to allow for higher still water bending moments to facilitate loading or unloading where the influence of wave forces is very small and only apply to ships with full unrestricted modulus. Because of their generality, the bending moment associated with the reduced wave bending stress cannot possibly represent actual conditions and, therefore, a comparison with the methods described in the Paper would be meaningless.

The philosophy adopted for transverse and local strength aspects is identical to that applied for longitudinal strength, in that comparative loads for a base service as well as the restricted service are used to assess requirements. Some local strength problems, such as strength of the bottom forward structure, are extremely dependent on environmental conditions, whilst the subject of transverse strength as a whole is not as sensitive to variations in applied loads.

In response to the suggestion of an Appendix to the Paper outlining the calculation procedure in a typical case, I have given, in the broadest possible terms, an outline of a recent strength investigation carried out by the Specialist Services Group of Hull Structures Department for the Canadian Government. Although this particular study was extensive, the procedure is typical.

To Mr. Taylor:

I would like to thank Mr. Taylor for this descriptive comments on the processes involved in the assessment of ship strength, and in particular, his simple explanation of the complexities of full-scale analysis.

To Mr. Sullivan:

Mr. Sullivan raises the very important role of damage statistics, and in doing so, highlights an important omission from the paper.

In most cases, where it is necessary to assess strength requirements for a new service, no operational experience exists and, therefore, no damage statistics will be available. However, the only way a base service can be considered acceptable is by an examination of damage statistics relevant to that service. This is done using the T.R.O. Data Base, which was the subject of a recent L.R.T.A. paper by Mr. Sullivan. Assesment of damage statistics has been carried out on a number of occasions for Hull Structures Department by the Technical Records Office and used to confirm or deny the suitability of the chosen base in both general terms and for specific ship details.

To Mr. Boltwood:

In the use of theoretical techniques, all assumptions should be questioned in specific applications. The particular point raised by Mr. Boltwood regarding the applicability of the strip theory in relation to non-linearities is of course relative, as most ships have changing forms above the still water line especially at the ends.

Based on experience, the most important element of the total mathematical model is the definition of the environment, and with judicious choice of the base service, the strip theory can still be used to assess relative increases or decreases in wave induced responses. If experience of a suitable base service is not to hand, or the environmental conditions of the only available base is far removed from the proposed service, then calculations should normally be checked by model tests using spectra from the environmental analysis. Alternatively, a lower total stress criteria could be used until some relevant full-scale operating experience becomes available which would then have the effect of non-linearities built in.

Analysis in regular waves is considered as a sub-set of the model for irregular waves. Therefore, if a system is highly non-linear it is best subjected, as above, to the most appropriate short-term extreme irregular spectrum obtained from the environmental analysis. At present this is best achieved by model tests.

During the writing of the Paper, I did consider including a worked example, but found that its extent would be inordinately large. I, therefore, opted for a comprehensive list of references to cover all theory and applications. The majority of elements of evaluation are carried out using standard unrestricted documentation as referenced, and these contain worked examples. The exception is the fundamental wave data analysis which is covered in some detail in the Paper and this should only be undertaken with considerable care and specialist advice.

To Dr. Kamtekar:

I am pleased that Dr. Kamtekar has highlighted the fact that advice on strength requirements can be given to Clients based on methods less rigorous than those described in the Paper. However, I would not agree that relaxations in strength requirements are permitted. The approach is rigorous because safety is involved. Anything less rigorous will necessitate a higher factor of safety.

An example of such a case is the delivery voyage of a vessel designed for a restricted environment having to use a route where wave conditions will be more severe than

those it will experience in its normal operational mode. The procedure involves a comparison of the wave heights and periods likely to be encountered on the voyage compared with those considered representative of unrestricted service. This gives a reduction factor to be applied to the Rule wave bending moment which is appropriate to a 20 year life in unrestricted service. This may be factored again, within certain restrictions, to take account of the short duration of the voyage.

This procedure can only be applied where a certain standard of wave data is available, and in view of the less rigorous approach, one must adopt a higher factor of safety by a limitation of the total vertical bending stress during the voyage.

To Dr. Ramzan:

The second order forces to which Dr. Ramzan refers are not considered relevant to the assessment of ship strength.

Second order forces, or wave drifting forces as they are commonly known, means that the forces are quadratic functions of the height of the incident waves. Such forces occur at the frequencies of wave groups which are much lower than the primary wave frequencies. These group frequencies can be obtained from the low frequency beat or pulse of the square of the height of the incident waves and the resulting second order forces only become important in say moored systems, where there may be a resonant response frequency close to the group frequency.

APPENDIX

Outline of the Calculation Procedure used to Assess Strength Requirements for Ships Operating within Restricted Service Limits.

Objective:

— To specify strength requirements to operate Great Lakes Type Bulk Carriers in a defined area of the Gulf of St. Lawrence, outside their normal limits of operation.

Main Input:

— Structural plans and loading conditions for three typical ships, covering a range of lengths.

— Scatter diagrams of wave height and period, produced by hindcast analysis of long-term wind data for positions representative of the new service and the base service.

— Strength requirements for the base service, which is the normal Great Lakes Operation dictated by the 1968 Interim Ottawa Strength Standard.

— Analysis of damage statistics for the base service.

Analysis of Wave Data:

— From the wave data supplied, obtain the best fit Weibull distribution parameters from wave height statistics for individual wave period groups, and probability densities of period groups, for the base and the proposed services.

— Check the raw data and predicted maximum wave heights against any available relevant measured data.

— Check the long-term predictions of wave height against values from extreme value analysis.

— Check the behaviour of wave distribution parameters in long-term calculations of ship response.

Evaluation of Ship Responses:

— Run the LR. SHIPS System, modules 1-5, to produce still water loads, and module 6A to prepare input for the strip theory program.

— Run the strip theory program, LR257Ø for a range of speeds, headings and loading conditions; main input being hull form data and total weight distributions.

— Check the output from the strip theory program.

— Run the programs LRS2 and LR257X, to obtain long-term predictions of low frequency wave-induced vertical bending stress, vertical shear stress, roll, pitch and relative motion. The main input to these programs is a definition of sea spectrum and wave distribution parameters for both services.

— Run the program LRP1M15, for analysis of springing with combined low and high frequency stresses.

— Correlate with any relevant full scale measurements available.

— Run the program LR323, to estimate the relative change in fatigue life of typical welded joints.

— Estimate the bottom slamming impact pressures for both services and the capability of the existing structure in way.

— Run the program LRP1M12, to obtain girth pressures for load input to NASTRAN for double bottom grillage and transverse ring frame analyses.

— Examine the buckling strength of panels showing high increases in stress between the base and the proposed services.

— Select design cases and obtain the percentage increase in relevant responses, and hence the necessary increase in structural capability.

Results of the Investigation:

— A recommended increase in midship modulus based on relative increases in combined wave bending with springing stress and shear stress.

— A recommended local increase in scantlings based on transverse strength analysis, buckling analysis and slamming analysis.

— Recommendations regarding fatigue life of structural connections.

— An overall check that the recommendations above are consistent with the base service and unrestricted seagoing service.

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RECIPROCATING COMPRESSORS

Bharath S. Rajan

Paper No. 5. Session 1979-80

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RECIPROCATING COMPRESSORS

by Bharath S. Rajan

1. INTRODUCTION AND HISTORICAL BACKGROUND

1.1 Introduction

Compressed air and gases play an important part in modern industrial societies. In this paper "gas" is considered in its widest physico-chemical sense, air being the gas most widely used.

The field of application of gas compression by reciprocating machines is very wide. Machines range in discharge pressure from 0.5 bar, used in instrument air applications, to pressures in excess of 5000 bar, used in the production of low density polyethylene. The power to drive these compressors range from a few watts to megawatts.

The basic thermodynamics of the compression process has been analysed and was known to a large extent by the first half of this century. This basic thermodynamic analysis is detailed in standard thermodynamics textbooks. However, this technique of mathematical modelling and analysis was extended considerably since 1949 and by 1974 the number of variables that could be considered in this analysis was 33. Today this technique of mathematically modelling the gasflow and being able to predict the behaviour of the compressor components in a closed circuit fluid flow (as in hermetically sealed refrigerant compressor systems) is accurate enough to give compressor designs in which 98% of compressors have almost infinite lifetimes.

The reciprocating compressor is defined as a machine in which gas is moved by a piston reducing the volume and hence raising the pressure of a quantity of gas trapped in a cylinder. The flow is controlled by the action of valves, either positively activated or automatically operated by the pressure differential across them.

The paper will evaluate the selection, use and future of compressors of this type in the United Kingdom.

A typical compressor family is shown in Fig. 1.

1.2 Historical Background

Compressors can be traced back to the bronze age, the earliest compressor consisting of leather bellows with flaps of material to act as inlet and delivery valves (Fig. 2). The date of invention is uncertain but certainly predates 1700 B.C. Various ancient texts describe compressors. Hand operated piston compressors with cylinders of bamboo trunks and wooden pistons were used in India, Egypt and China long before the Christian era (Fig. 3). The most significant among the ancient inventions were Hero's water trompe, a hydraulically operated compressor and Vitruvius' invention of a cylindrical, piston and cylinder bellows unit.

An important advance was the invention by Leonardo da Vinci in the 15th century, of the multiple valve with lightweight elements and streamlined ribs. In the 18th century various patents were granted for positive displacement compressors: in this period the thermodynamic implications of

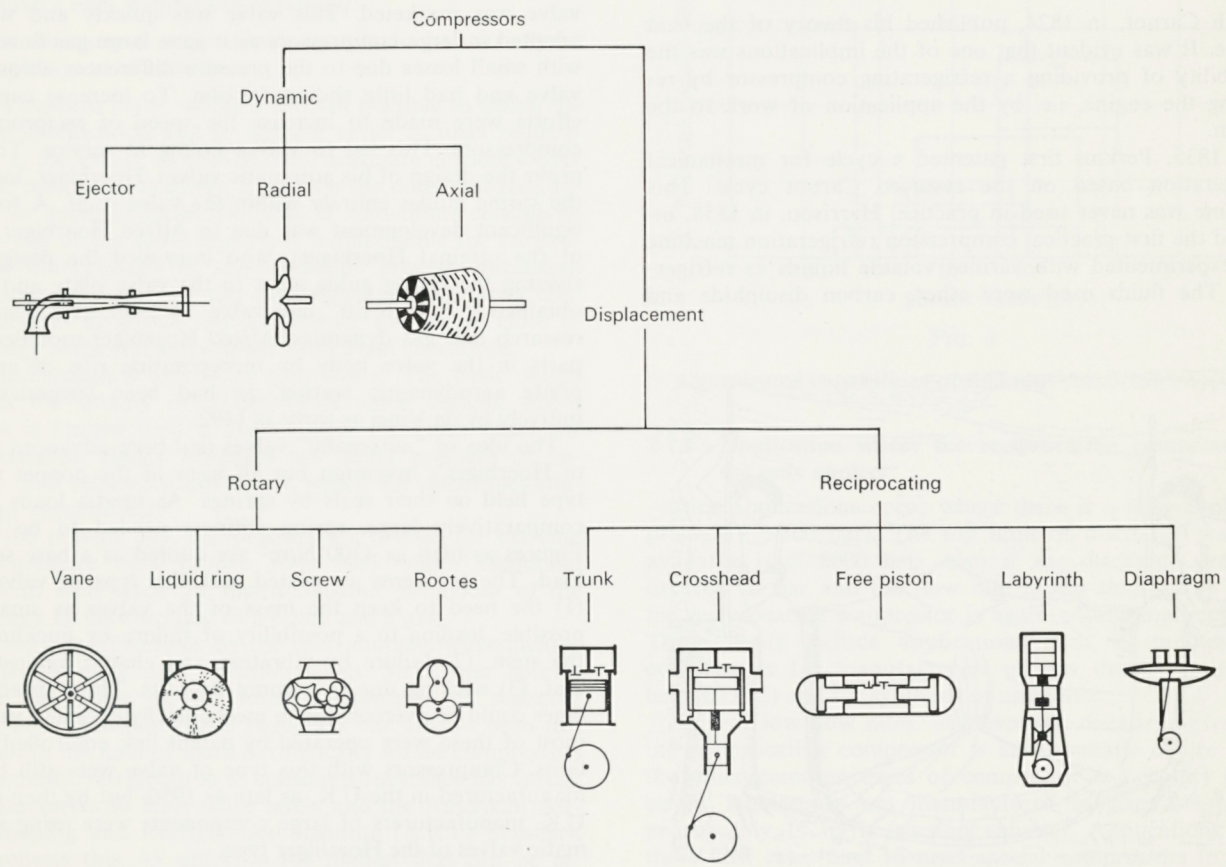
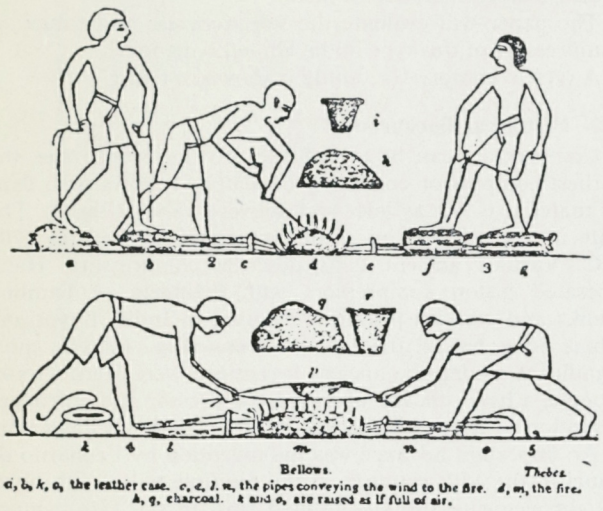


FIG. 1

The compressor family tree.

the compression process were first appreciated. Various developments followed rapidly and patents were granted in both the United Kingdom and France for compressors of increased efficiency. The first attempt to cool the compressed gas was in 1872, by the direct injection of water into the compressor cylinder. However, the rate of corrosion in this type of compressor, together with hazards of water hammer within the cylinder, led to the adoption of a water jacketed cylinder and also intercooling of the gas.



a, b, k, a, the leather case. c, e, l, m, the pipes conveying the wind to the fire. d, m, the fire.
h, q, charcoal. k and o, are raised as if full of air.

FIG. 2

Bellows—the earliest compressor.

Sadi Carnot, in 1824, published his theory of the heat engine. It was evident that one of the implications was the possibility of providing a refrigerating compressor by reversing the engine, i.e. by the application of work to the system.

In 1835, Perkins first patented a cycle for mechanical refrigeration based on the reversed Carnot cycle. This machine was never used in practice. Harrison, in 1858, invented the first practical compression refrigeration machine and experimented with various volatile liquids as refrigerants. The fluids used were ether, carbon disulphide and sulphur dioxide. In 1873, Linde used ammonia as a refrigerant and in 1876 Pictet patented the first water cooled ammonia refrigerant compressor.

FIG. 3

Wooden piston bellows for a forge.

During this period (mid to end 19th century), various other ideas for positive displacement compression were advanced. Rootes blowers, liquid ring and screw compressors were patented. The vane compressor was patented in 1892. Problems arose with these rotary machines due to lack of machine tools capable of manufacturing components to sufficiently fine tolerances. Nevertheless, they had some success in low pressure applications (e.g. blowing of cupola furnaces etc.).

At this stage the need for larger capacities of compression plant prompted interest in aerodynamic type machines. Initially these performed poorly and a pressure increase of only 1.5 lb/in^2 (0.1 bar) could be generated. Rateau, in France, experimented with dynamic compression and was able, in 1899, to design a centrifugal fan with a compression ratio of 1:1.6. Thereafter, depending on the conditions to be met, the aerodynamic type of compressor was also a machine to be considered as a viable alternative.

In the early years of the 20th century demand for compressed air grew so rapidly that reciprocating compressors were replaced by rotary compressors, especially in the mining industry, where relatively large volumes of flow at relatively low pressures were required. In 1911 the Victoria Falls and Transvaal Company installed turbo compressors in mines, this being the first large-scale application of aerodynamic compression.

During these developments it became apparent that the components most at risk in reciprocating compressors were the valves. Until the end of the 19th century manufacturers had tended to use mechanically operated poppet valves in reciprocating compressors. In 1894 the first Hoerbiger disc valve was marketed. This valve was quickly and widely adopted in large compressors as it gave large gas flow area with small losses due to the pressure differences across the valve and had little sliding friction. To increase capacity efforts were made to increase the speed of reciprocating compressors. This led to valves failing in service. To improve the design of his automatic valves, Hoerbiger, located the spring guides entirely within the valve itself. A further significant development was due to Alfred Hoerbiger (son of the original Hoerbiger), who improved the design by riveting the spring guide arms to the valve plate and thus obtained the "high lift" disc valve. In 1936, as a result of research into gas dynamics, Alfred Hoerbiger modified the parts in the valve body by incorporating ribs of appropriate aerodynamic section, as had been suggested intuitively by da Vinci as early as 1492.

The idea of "automatic" valves had been advanced prior to Hoerbiger's invention but all were of the poppet valve type held on their seats by springs. As inertia loads were comparatively large, spring stiffness needed to be high. Figures as high as 4300 N/m^2 are quoted as a base spring load. The problems associated with this type of valve are (1) the need to keep the mass of the valves as small as possible, leading to a possibility of failure by buckling of the stem, (2) failure by vibration and chatter against the seat, (3) sticking due to gummy deposits. These disadvantages could be overcome with mechanically operated valves: most of these were operated by patent link controlled motions. Compressors with this type of valve were still being manufactured in the U.K. as late as 1950, but by then most U.K. manufacturers of large components were using automatic valves of the Hoerbiger type.

Efforts were made to increase the output of reciprocating compressors per unit weight and volume of the machine by the use of Vee, W and radial configurations of cylinders, not least for refrigeration and air-conditioning applications.

Higher rotational speeds of the crankshaft became practical as the drive changed from reciprocating steam engine to D.C. and then squirrel cage A.C. motors. This led to the production of lower torque compressors of lighter construction with higher relative speeds between the moving parts, leading to a demand for better lubricants.

Even though rotary compressors were being developed rapidly, reciprocating compressors continued to hold the market where medium or low volume flows and high output pressures were required. High pressure compressors built as an integral part of heavy oil engines were first commissioned for use in blast injection systems where high pressures of around 1000 psi (c. 70 bar) were required. This type of construction was then extended into compressors for the chemical process industry, where the compressor cylinders were on a horizontal plane and the engine cylinders on the vertical plane, all pistons being driven by the same crankshaft.

The important development of quick freezing by Zarotchenzeff in 1930, opened the way for large-scale transport of foodstuffs over the world, opening even larger markets for refrigerant compressors. In the years of World War II the hermetically sealed compressor was developed and these small units then replaced the "open" type of compressor for domestic refrigeration.

1.3 Present Day Compressors

The present generation of large reciprocating compressors have been designed to meet four basic requirements of industrial users:

1. Perform the required duty efficiently.
2. Operate adequately at a wide range of plant conditions.
3. Have a high standard of reliability.
4. Enable normal maintenance on site to be carried out rapidly and effectively.

In a modern plant, whilst it is often possible to define the design specification and so make it easier to meet requirement 1, the ability to operate with adequate efficiency over a wide range (requirement 2) may be the dominant requirement in some applications. This is sometimes considered to be one of the most important requirements for reciprocating compressors in the chemical process industries. Requirement 2 leads to the incorporation of capacity control devices to enable the compressor to operate close to its design point efficiently under most plant conditions.

Requirements 3 and 4 are interrelated. The basic design affects the quality of maintenance since designs where access is limited tend to have longer offstream times for maintenance. Hence designers are under pressure to improve both reliability and access, which are sometimes conflicting requirements.

In the present day, compressors are needed for extreme high pressure duty (above 1000 bar) where additional problems arise since the thermodynamic behaviour of the fluid may lie between that of a liquid and a gas.

Modern specifications by the user almost always include permissible noise and vibration levels. Strict user specification has made manufacturers concentrate on reducing noise and vibration. Noise reduction has always been important in the field of small hermetically sealed compressors for domestic refrigeration as consumer resistance has forced manufacturers to limit noise levels and the American Air-conditioning and Refrigeration Institute (A.R.I.) Standard 270 reflects this. 45 dB(A) is the highest that can be regarded as acceptable for this application and current practice aims at a figure about 35 dB(A). The Ministry of Defence (Navy) specifies extremely low noise levels on all compressors and conducts stringent noise tests before acceptance of equipment for submarine use.

With escalating energy costs, power economy is an increasingly important feature in the marketing of compressors. There are various schemes to recover the energy input to the compressor: including using this energy for space heating and wash water heating. The Department of Energy has issued a fuel efficiency booklet (No. 4) to encourage this trend.

2. THE ROLE OF RECIPROCATING COMPRESSORS IN AIR AND GAS COMPRESSION

2.1 General

Making a choice of compressor for a particular duty can be difficult since the areas of application of the various types of compressor overlap. Hence we can consider two types of application:

1. Where the reciprocating compressor is the only choice.
2. Where other types of compressor have to be considered.

The graph (Fig. 4) delineates the area of application of the various compressor types.

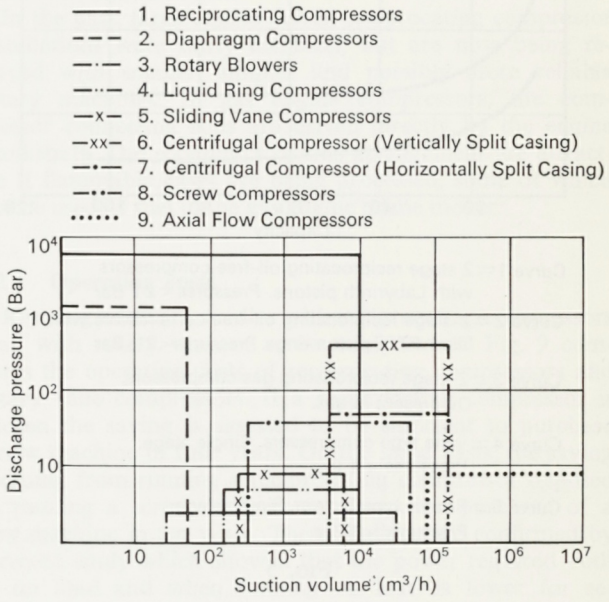


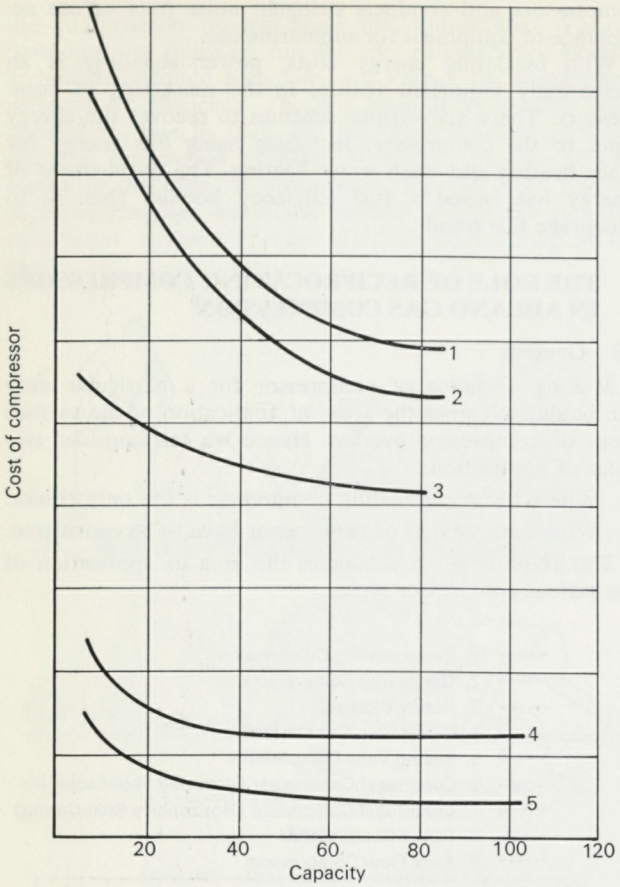
FIG. 4

Operational capabilities of different compressor types.

2.1.1 Application where the reciprocating compressor is the only choice

Such applications occur where there is a high discharge pressure (>500 bar). The top limit of discharge pressure available is c. 8000 bar. Also if the discharge pressure exceeds 70 bar and the flow rate is less than 6×10 m³/h the reciprocating compressor is again an automatic choice. These limits include applications such as process gas compressors for manufacturers of low density polyethylene (LDPE) and for synthesis of ammonia.

At very low flow rates, whatever the discharge pressure, the reciprocating compressor is an automatic choice since the other common types of compressor (e.g. rotary vane, screw, Rootes are not manufactured in sizes below approximately 15 m³/h (suction volume). Applications with these flow rates tend to need special compressors (e.g. oil free delivery): unusual reciprocating designs such as diaphragm compressors are often cost effective for such applications.



Curve 1 = 2 stage reciprocating oil-free compressors with Labyrinth pistons. Pressures < 21 Bar

Curve 2 = 2-stage reciprocating oil-free compressors with filled PTFE piston rings. Pressures < 21 Bar

Curve 3 = 2-stage reciprocating gas compressors. Oil present in gas.

Curve 4 = vane type compressors. Single stage. Pressures < 4 Bar

Curve 5 = Rootes type blower. Single stage. Pressures < 1 Bar

FIG. 5

Cost comparison of different compressor types.

2.1.2 Application where other types of compressor should be considered

In applications outside the fields covered in 2.1.1, other types of compressor must be considered. However, at flow rates greater than 10^4 m^3/h (suction volume) the aerodynamic type compressor is now used almost exclusively, since its thermodynamic efficiency is greater than that of multi-stage intercooled reciprocating compressors.

Brightwell defines the lower limit of discharge pressure for application of reciprocating compressors as 5 psi (3500 N/m^2). The applications in this region are limited, usually involving large flow rates (e.g. booster charging in I.C. engines) and are normally met by Rootes blowers or aerodynamic type machines.

2.2 Cost of Compressor Installations

After the compressor duty has been decided, quotations for the capital cost can be obtained from manufacturers, but the capital cost of the compressor alone is insufficient for making a final selection. The following important items should always be considered:

1. Capital cost of compressor.
2. Cost of foundations.
3. Floor area required.
4. Cost of prime mover.
5. Operating costs.
6. Maintenance costs.

2.2.1 Capital cost of compressor

Curves of compressor unit costs (per unit capacity) are shown in Fig. 5. Though these curves were published in 1966 the relative positions of the cost curves remain substantially the same and show that the initial cost of all positive displacement compressors is high compared to aerodynamic machines of the same capacity. Further, among positive displacement types, reciprocating compressors have higher unit costs. Of the reciprocating compressors considered the highest unit cost is for reciprocating compressors with labyrinth pistons and seals. Hence, this type of compressor is not popular at the present time, except in some refrigeration applications.

The variation in cost of various makes of reciprocating compressors now being manufactured in the U.K. are shown in Fig. 6.

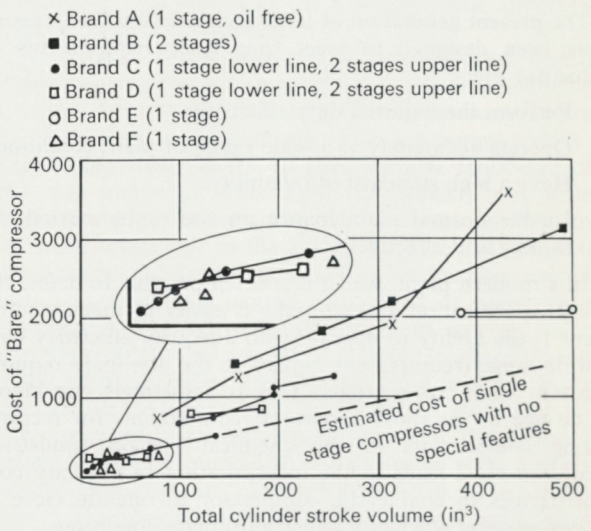


FIG. 6

Cost comparison of reciprocating air compressors available in the U.K.

(Courtesy of Mr. Hoare.)

2.2.2 Cost of foundations

Because of the inherent good balance of rotary aerodynamic type compressors, they require foundations no larger than that required to support the prime mover. This is also the case with rotary vane type and liquid ring type positive displacement compressors. However, by using opposed, Vee and W configuration reciprocating compressors, the out of balance forces and hence the foundations needed can be greatly reduced. As a general rule, the foundations are designed to support the reciprocating compressor and then their dimensions are extended in length to support the prime mover. This type of foundation is not strictly necessary except where the prime mover and the compressor are mounted on the same skid and hence forces are transmitted through the skid.

There are modern reciprocating Vee compressors which have a sufficiently low level of out of balance forces to be capable of free standing operation and economies are possible in production of this compressor if enough care is taken at the design stage.

2.2.3 **Floor area required**

Floor area involves both a capital and a running cost (e.g. overheads and rates) and hence a minimal floor area requirement may be an important consideration except in particular applications such as air compressors for main starting air on board ships. In such exceptional cases, the available floor area may be decided by other criteria (e.g length of main propulsion machinery etc.) probably leaving ample space for installation of compressors.

Reciprocating compressors have the highest unit space requirement compared to all other types of compressor, so leading to a reduction in its use where space is a major consideration. An example is in the field of non-hermetic refrigerant compressors, where the reciprocating compressor was universally used, but is now facing a strong challenge from screw compressors. However, in some applications in the lower power ranges (e.g. cold storage plant etc.) extensive provision is usually made at the outset for expansion of the plant. Thus excess floor area is often available in the compressor house, and so the floor area required by a compressor is not a particularly critical parameter.

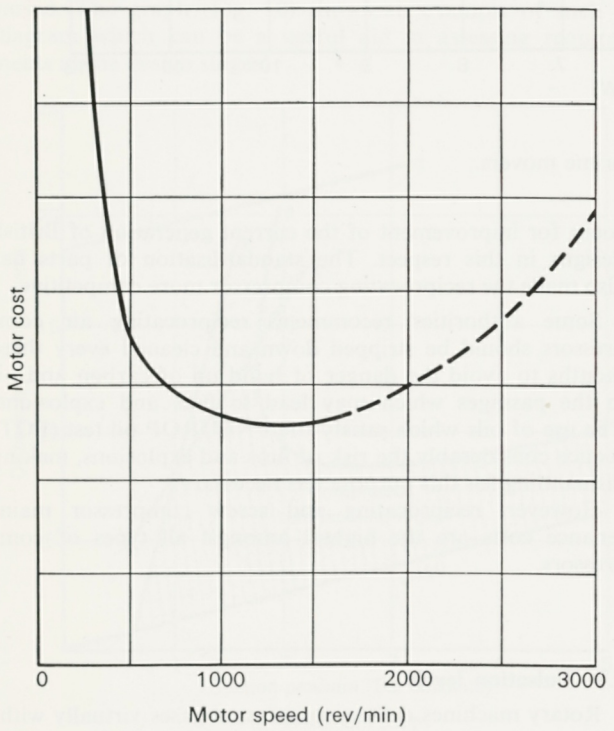


FIG. 7

Curve of motor cost.

2.2.4 **Cost of prime mover**

Figure 7 shows the electric motor cost as a percentage of compressor cost versus compressor speed. The minimum costs occur at about 1300 rev/min so enticing compressor manufacturers to aim for this compressor speed. Direct on line starting is the most common method of start, with induction motors providing the drive and above 450 bhp (330 kW) synchronous motors are used. In the very high power range (>1 MW) gas engine or turbine power units are used. The turbine drive has the advantage that it is capable of large speed variations which can be used as a method of controlling the output. However, the cost of these prime movers is high and the modern trend is to utilise one compressor at 100% of the required capacity rather than two machines of 50% capacity to reduce the initial cost. Under these circumstances, output control and part load performance assume additional importance.

In industries where boilers and process steam equipment already exist (e.g. chemical process industries), the most suitable prime mover is likely to be the steam turbine utilising the exhaust steam for the chemical process and driving a high speed compressor (by eliminating gearing an improvement in efficiency of $2\frac{1}{2}\%$ may be achieved). If there is no other requirement for steam the steam turbine drive is the most expensive, in both capital cost and operating costs, since an expensive boiler, condensing set and associated equipment must be provided (Fig. 8).

Utilisation of a gas turbine drive is cost effective only in circumstances where the heat in the exhaust gases can be utilised in other processes e.g. heating reactor vessels in nitric acid manufacture.

In the past, large engine driven reciprocating compressor installations were fairly common, but are now being replaced with smaller, simpler and possibly more reliable rotary machines. In gas engine compressors, the compressor connecting rods are driven directly by the engine crankshaft. The economics of this arrangement are attractive if flammable gases are being processed, some of which can be used as fuel in the gas engine prime mover.

2.2.5 **Operating costs**

Running costs are smaller with reciprocating compressors than with rotary vane or screw compressors. Fig. 9 compares the operating costs of reciprocating compressors and rotary vane compressors. If a reciprocating compressor is chosen the saving is assessed to be sufficient to purchase a new machine in four years. On the same basis, the saving accruing from running a reciprocating compressor opposed to running a screw compressor allows the purchase of a new machine in ten years. These findings are confirmed by a recent study which showed that the power required both at no load and when running on load is lower for reciprocating compressors than for comparable screw compressors. It is estimated that approximately 50% of total compressed air cost is for power requirements presently costing £55 to £110 per year per horsepower (0.746 kW) rated. Costs are rising at present by 15% per annum and a cost comparison with a 28 m^3/min capacity compressor at suction conditions working at a load factor of 75% running for 4000 hours per year showed a saving of £3000 in favour of a reciprocating compressor against a screw compressor. The reciprocating compressor would pay for itself, by savings in *three* years at current prices.

Various improvements are being made in screw compressor design: though the first cost is less it still remains more expensive to operate. The improvements increase part load efficiency but are at the expense of simplicity and increase the maintenance costs.

2.2.6 **Maintenance costs**

Maintenance costs are difficult to assess, but 3.5% of the capital cost of a new compressor per year is considered a valid estimate. However, maintenance costs as a percentage of new compressor costs do not vary much with time and even old reciprocating compressors are not relatively more

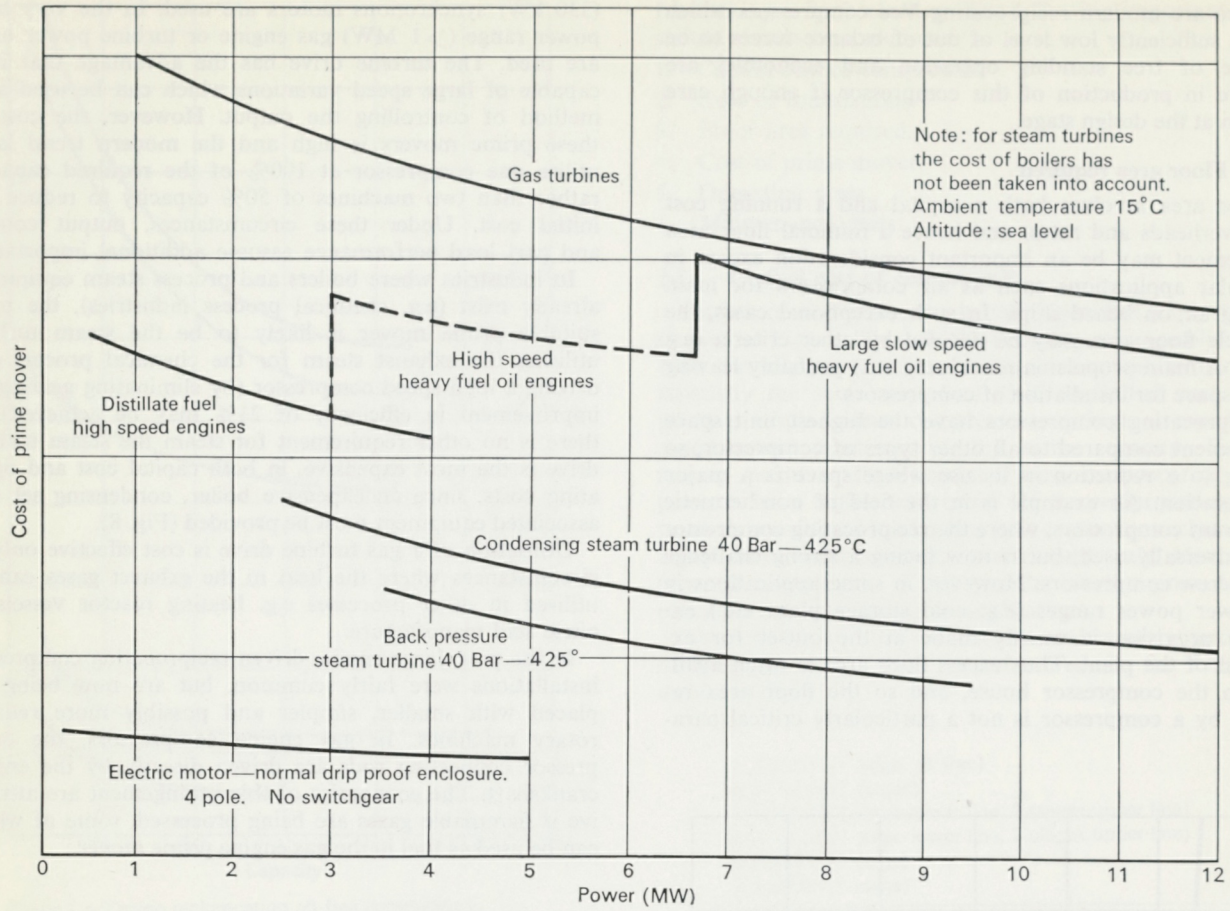


FIG. 8

Cost comparison of prime movers.

expensive to maintain. Some of the improvements to reduce maintenance in reciprocating compressors are:

1. Large openings to give access to piston rod glands.
2. Removable crosshead guides which can be given a second life by a 90° turn.
3. Crankshaft bearings of the spherical or cylindrical roller type.

Though various American manufacturers have incorporated these improvements in their designs, British manufacturers have not generally followed suit and hence there is room for improvement of the current generation of British designs in this respect. The standardisation of parts has also made the reciprocating compressor more competitive.

Some authorities recommend reciprocating air compressors should be stripped down and cleaned every three months to avoid the danger of build up of carbon and oil in the passages which may lead to fires and explosions. The use of oils which satisfy the PNEUROP oil test (POT) reduce considerably the risk of fires and explosions, making dismantling for this purpose less necessary.

However, reciprocating and screw compressor maintenance costs are the highest amongst all types of compressors.

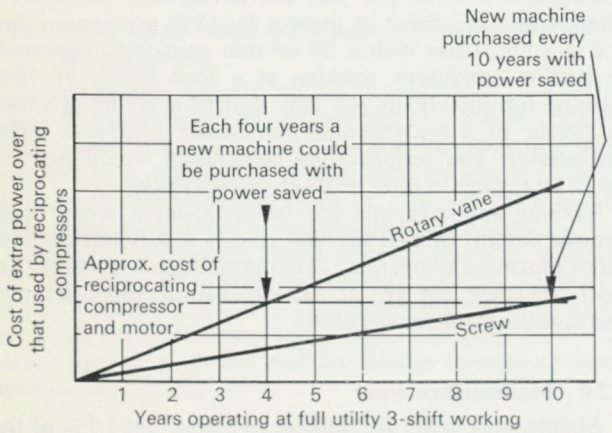


FIG. 9

Extra running costs incurred by rotary vane and screw machines.

2.3 **Pulsation levels**

Rotary machines deliver compressed gases virtually without pulsation but all positive displacement machines, with the exception of the liquid ring compressor, deliver a pulsating flow. Of these the reciprocating compressor discharges at a basic pulsation frequency which is the compressor speed (if single cylinder and single acting) whilst screw, sliding vane and Rootes type compressors have pulsations at the passing frequency of the lobes or vanes and so at a higher multiple of the rotational speed. The pulsation amplitudes in reciprocating compressors are high compared to all other designs. Some maximum pulsation criterion should be adopted in the design of larger reciprocating compressors to provide protection for the piping in such installations.

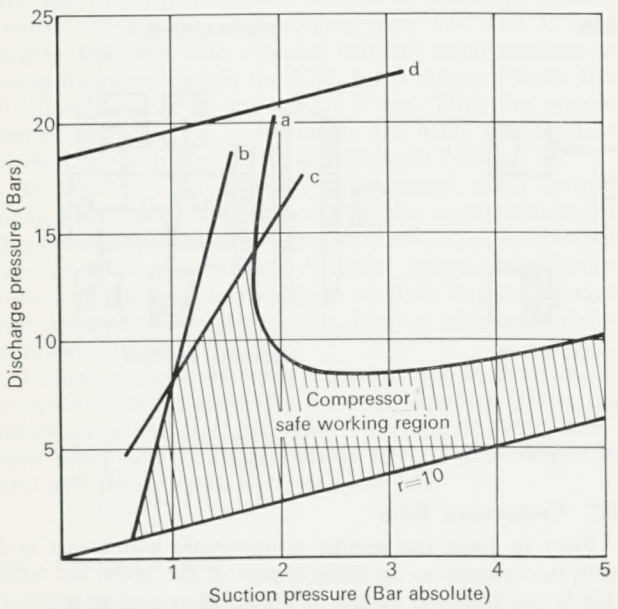
2.4 Capacity Control

Aerodynamic type machines can become unstable and the flow will surge if the flow rate is too low relative to the design flow rate. This can be a problem with process gas compressors where load may fluctuate considerably such as in line packing compressors in gas transmission stations. Thus the flexibility with which a reciprocating compressor can operate over a wide range of conditions can be a major attribute in its favour. Capacity control can be achieved by the methods described in Section 3.16, giving the reciprocating compressor an advantage over the screw compressor in which the capability of capacity control is more limited.

The capability for capacity control of other types of positive displacement compressor are comparable to the reciprocating compressor but as their operating ranges are comparatively limited (Fig. 4) the reciprocating compressor remains the choice where widely varying plant conditions occur.

Some large capacity plants have reciprocating compressors as booster compressors. Very large turndown ratios are required in these compressors as they are usually supplied from a number of compressors (usually aerodynamic type) in parallel. The number of primary compressors in parallel being varied as the flow rate demands.

One method of determining the range of operation necessary for a booster compressor is using the "line-pressure diagram" which is a plot of compressor discharge pressure versus suction pressure when the capacity is varied. The graph (Fig. 10) shows an example of such a diagram which can be a useful aid in assessing requirements at the design stages.



a Maximum b.h.p.
b Minimum flow
c Maximum T_D
d Maximum rod load

Shaded area denotes safe working region

FIG. 10

The "line pressure" diagram.

2.5 Oil Free Delivery

The most common special requirement is that the gas discharged be free of oil. The only type of compressor which cannot deliver oil free gas is the sliding vane type. The reciprocating compressor can deliver oil free gas either by the use of self-lubricating piston rings and seals, or by the use of labyrinth pistons and seals, or by the use of a diaphragm. Oil free delivery is only available from the screw compressor if the pressure ratio is small (<2): larger pressure ratios (up to 6) can be achieved if oil is injected as a coolant. Where the flow rate is sufficient ($>7\times10^3$ m^3/h suction volume) aerodynamic type machines may be considered since oil does not come into contact with the gas.

Some manufacturers of screw compressors achieve oil free delivery by using silicone fluids or water injection to seal the rotor lobes but an objection may be that *oil free* is generally accepted as meaning no foreign fluid in the process gas. There is also objection to the injection of liquids into a space where even a slight excess could result in mechanical damage.

In an analysis of 203 compressor systems installed in the U.S.A., it was found that 54 required oil free delivery and 40 of these oil free systems incorporated reciprocating compressors. This suggests that reciprocating compressors are still competitive in this field.

2.6 Vibration Levels

Here the vertical reciprocating compressor is at a disadvantage, since all other types have lower vibration levels. If this is an important criterion, reciprocating compressors, if available must be chosen in opposed Vee or W configurations, where vibration levels can be comparatively low. In modern practice, low vibration levels have been achieved in large capacity compressors having a balanced opposed piston configuration and levels as low as $\pm$ 0,05 mm ($\pm$ 0.002 in) amplitude at maximum output have been quoted. If low speed machines, which may have a relatively low vibration level, are chosen usually a belt drive is required and a loss in efficiency of between 5% and 3% accepted due to the belt drive.

2.7 Noise Levels

Noise in reciprocating compressors continues to be a problem, although they are significantly quieter than screw or Rootes type compressors. The screw and Rootes type compressors generate noise at higher frequencies and so give higher noise levels when plotted on the dB(A) scale which is weighted against higher frequencies. Other types of compressor have much the same level of noise as the reciprocating compressor and it is claimed that noise generated by axial or centrifugal compressors can usually be "filtered" fairly easily. In the author's experience this may not always be possible, e.g. in I. C. engine turbo blowers, where the attached piping can give rise to substantial amounts of high frequency noise.

2.8 Overall Assessment

The reciprocating compressor suffered a decline in use due to higher initial and maintenance costs not being sufficiently offset by its higher efficiency. In the past few years, design improvements have halted this trend. The concept of a packaged compressor has improved the relative position of the reciprocating compressor even further. Many of the air compression packages are oil free, the air being aftercooled and delivered dry.

The chief competitor to the reciprocating compressor is the rotary screw compressor, especially in the range of operation from 15 to 300 psi (c. 1 bar to 21 bar) in a capacity range of up to c. 7×10^4 m^3/h.

Arrangements for compressing air to the maximum pressure required and then reducing the pressure for other duties is uneconomic and it is better to match the compressor closer to the duty required which favours the

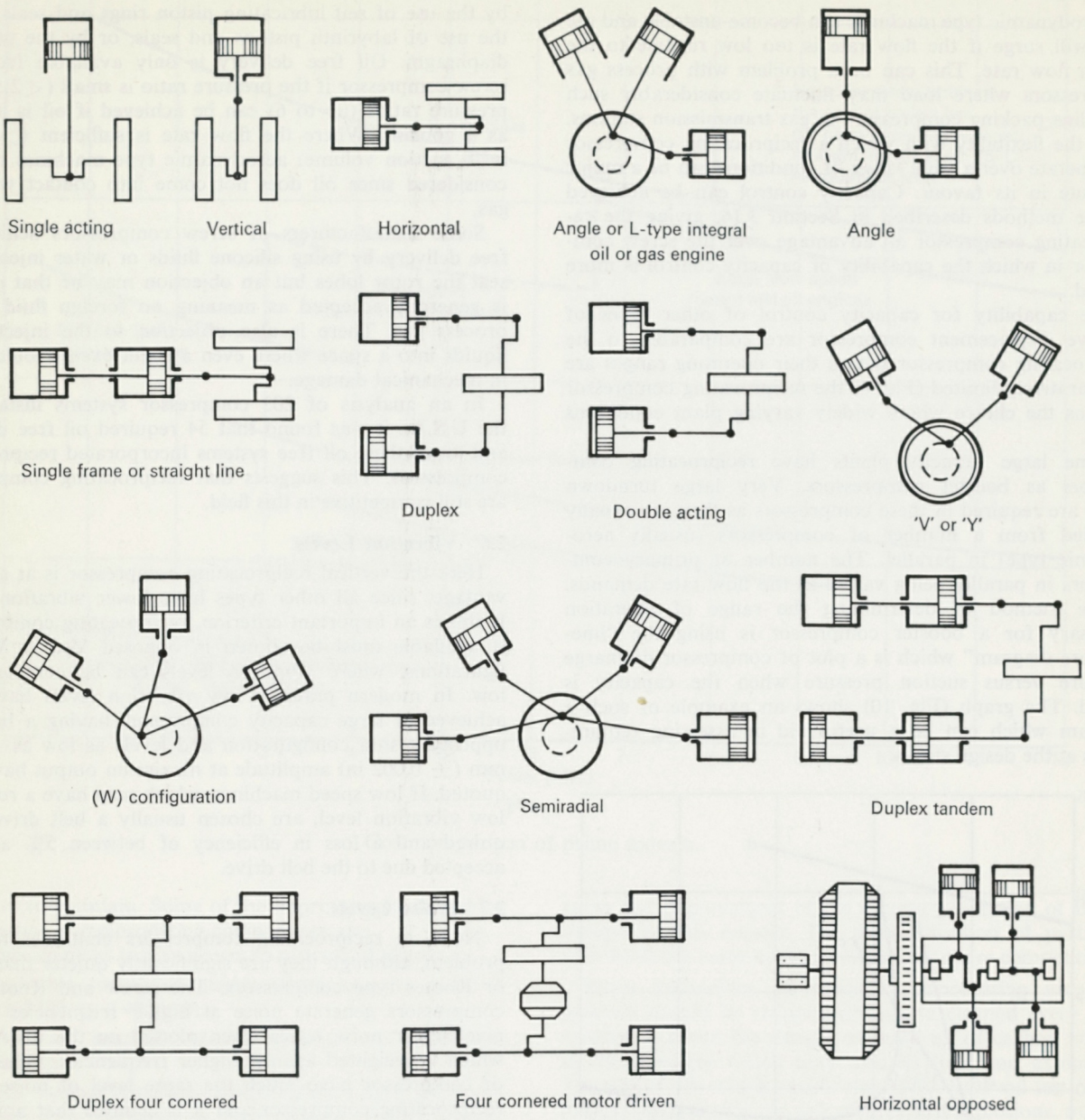


FIG. 11

Reciprocating compressor configurations.

reciprocating compressor, where capacity control can be achieved with little loss in efficiency.

In hermetically sealed compressors for domestic refrigeration and air-conditioning, reciprocating machines are dominant, since they are exceedingly reliable and have low noise levels.

The above arguments demonstrate that reciprocating compressors remain competitive for applications below 10^4 m^3/h (suction volume) capacity.

3. COMPRESSORS—HARDWARE

3.1 General

In modern practice, reciprocating compressor construction varies with the duty required. However, it is possible to make general comments on common materials for the components and the general approach to design.

3.2 Compressor Body

Prior to 1960, the smaller compressors had a cast body with the cylinder as an integral part of the body, but today this is not the case except in the smaller sizes of hermetically sealed refrigerant compressor.

In all other applications the compressor barrel is formed as a separate part which is then fitted to the body. In larger compressors, the body consists of crankcase and cylinder barrel jacket blocks. In smaller compressors the body forms only the crankcase whilst the barrel, which has a ribbed outer construction to aid air cooling, forms the upper body.

In almost all applications, except the very largest compressors (e.g. Peter Brotherhood E-range, Nuovo Pignone H-range etc.), the compressor body is made of cast iron. The material specifications vary, Meehanite cast iron or close grained cast iron being the most common. In the higher power ranges steel fabrication is the norm. Cylinder

frames are bolted onto the cylinder heads by long bolts in the higher power ranges and by short studs in the lower power ranges.

In a multistage compressor for high discharge pressures, the final and penultimate stages may be arranged outboard of the intermediate stages. This reduces the loading on the high pressure piston seals and allows any leakage of the working fluid to be recycled instead of being lost to atmosphere or building up in the crankcase.

The larger range of gas compressors are usually built to A.P.I. specification 618 and 11P. This specification does not specify that explosion doors be provided on the crankcase, but clause 2.9.8 allows for explosion relief devices to be specified by the purchaser and it is general practice to order these devices on compressors which have crankcase volumes in excess of 20 cubic feet (0.58 m^3). In the case of compressors which provide air for starting of ships engines, the classification societies require explosion doors on crankcases which have volumes over 0.60 m^3 or have cylinder bore over 200 mm. (Lloyd's Rules. Part 5, Chap. 2., Section 6).

3.3 Cylinder Configuration

Very many arrangements of cylinder configurations have been used and some of these are shown in Fig. 11, but not all of them are used in the U.K. today.

The most commonly used configurations today are the vertical in line, Vee, W, and horizontal opposed geometries. Vertical in line (single acting) configurations are used by a leading manufacturer of air compressors for discharge pressures over 2×10^6 N/m^2. Multiple cylinders per crank are the rule for the lower ranges of discharge pressure (unless for special applications). Vee, W-, and L (a 90 degree Vee with one cylinder vertical) configurations are being manufactured in the U.K. for a range of flows from 0.037 m^3/min to 60 m^3/min at 7 bar. With the opposed piston configuration, compressors are being manufactured in the U.K. with flows up to 88 m^3/min at 7 bar.

In the field of refrigerant compressors, small hermetic units have a balanced opposed piston configuration (180 degree Vee) but the larger open or semi-hermetic units have Vee or W- configurations. A major British manufacturer uses a double Vee configuration on their largest series and this incorporates eight pistons from a single crankshaft with two throws.

In gas compressors being manufactured in the U.K. for chemical process plant, the balanced opposed piston configuration is the most common. This type of compressor is now being manufactured with up to ten cylinders per unit and with power inputs of up to 14000 kW.

3.4 Cylinder Heads

Cylinder heads are often cast steel though close grained cast iron is sometimes used in smaller machines.

For discharge pressures of up to c. 10×10^6 N/m^2, the valves are usually assembled into the cylinder head but above this pressure the design of the cylinder head needs to be simple to withstand stresses due to (a) the delivery pressure (c. 100×10^6 N/m^2) and (b) a superimposed cyclical loading in the range 15×10^6 N/m^2 to 120×10^6 N/m^2. The solution adopted by some British manufacturers is to have a simple block cylinder head with a cross bore which can connect up to the valve housings in the main body of the compressor. This allows a flat disc design of cylinder head which can be manufactured from special fatigue resistant steels, with suitable radii at corners of possible stress concentration. These cylinder heads cannot be fabricated but have to be machined from a single block because of the behaviour of such steels in welded structures under cyclical loads.

3.5 Cylinder Liner

The material for the liners is usually cast iron, though bronze and stainless steel are used for particular duties. Whenever process requirements are such that oil or other lubricant can be used to reduce friction between piston rings and liner, close grained iron or spheroidal graphitic iron (S.G. iron) is almost always used. A modern trend is towards stainless steel liners, which can be used in both lubricated and non-lubricated service by appropriate choice of piston ring material. In compressors for air and the chemical process industry, liners are usually manufactured in one piece arranged so that a space for a cooling medium is left around the liner after assembly into the compressor body. As mentioned earlier (art. 3.1) in compressors with air cooling the liner forms the upper body of the compressor.

In refrigerant compressors the suction gas is usually drawn from the crankcase which acts as a reservoir for the gas returning from the evaporator. Here the liner arrangement in the compressor body is such that the gas flows from the crankcase over the outside of the liner providing cooling, and is then drawn through a valve into the cylinder bore. In this case the liner may not be in one piece but is part of a sub-assembly that incorporates a mechanism which can lift the moving element of the suction valve off its seat thus "unloading" the cylinder. The mechanism is usually operated by lubricating oil pressure, though in early models discharge gas has been used. In the present author's experience, care in putting together these sub-assemblies is necessary to ensure trouble free operation.

3.6 Bearings

Bearings in small compressors tend to be either tapered roller or ball bearings. In medium and large sized machines thin shell bearings are the rule.

The thin shell bearings used are usually of the trimetal type which do not require any scraping of the bearing and are "self bedding". One major manufacturer still uses steel backed white metal bearings which need bedding-in by scraping. In the author's experience "self bedding" bearings are a great advance and considerably reduce maintenance times when bearings require renewal.

Gudgeon pin bearings are usually of bronze though steel backed white metal bearings are also quite widely used.

Some manufacturers use ball or roller bearings for crankshaft bearings and white metal bearings for the connecting rod.

The thrust is usually taken up at a face on either the drive end bearing or free end bearing; one manufacturer incorporates the thrust face on the centre bearing on a three main bearing crankshaft.

3.7 Crankshafts

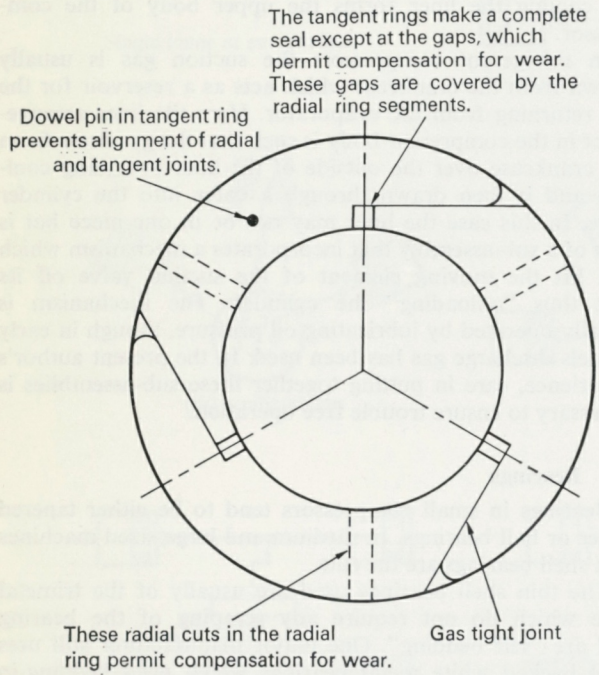
In some of the smaller compressors, cast iron or S. G. iron crankshafts are used but in the bulk of the compressors presently manufactured in the U.K., solid forged crankshafts are used. The material usually conforms to B.S. 1503. Some makers specify alloy forgings but normally heat treated forgings are specified (especially in compressed air service). Induction hardened and case hardened crankshafts may also be used and in the largest sizes of gas engine driven compressors one manufacturer uses built-up crankshafts.

3.8 Seals

Seals can broadly be divided into two classes (1) the shaft seal on the crankshaft which seals a rotating element and (2) the piston or piston rod seal where the elements are in linear motion.

3.8.1. Rotating element seals in compressors

The rotating shaft seal in air gas compressors (where the crankcase is not pressurised) is usually a scraper ring with a pocket for collection of the lubricating oil carried along the crankshaft. This pocket is allowed to drain into the crankcase through a drilled passage. The design in refrigeration machinery, where the crankcase is under pressure and acts as a reservoir for the refrigerant, has been well documented (e.g. Marine Engineering Practice, Volume 1). In most gas compressors the crankcase is not under pressure (i.e. the process gas is isolated from the crankcase by piston rod seals) and the construction of the shaft seal is similar to that on air compressors.



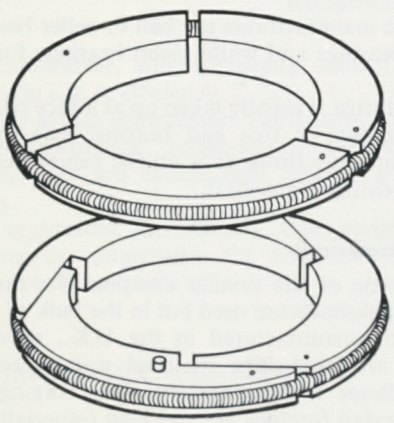


FIG. 12

Twin ring piston rod oil seal.
(Courtesy of Mr. R. S. Wilson.)

3.8.2 Linear motion seals in compressors

The piston rod seal must be compatible with gas. To avoid incompatibility and reduce frictional losses labyrinth designs of seal are available. The problems associated with these seals are:

1. The need for two guiding elements for the piston, leading to the problem of placement of the second guiding element (since the first can be placed in the crankcase but the second cannot).
2. Need for the piston to be self-centring.

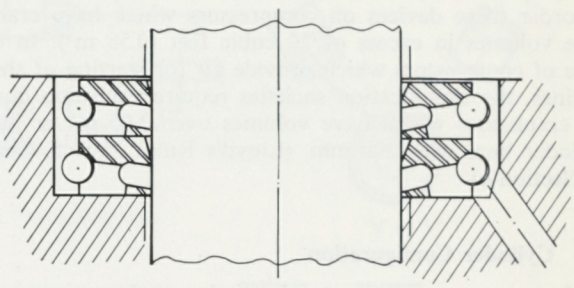


FIG. 13

Twin ring piston rod oil seal—cross section.
(Courtesy of Mr. R. S. Wilson.)

Seals which have mechanical contact with the piston rod are of various types, the segmented design being the most popular with British designers. Figs. 12 and 13 show an example of this type.

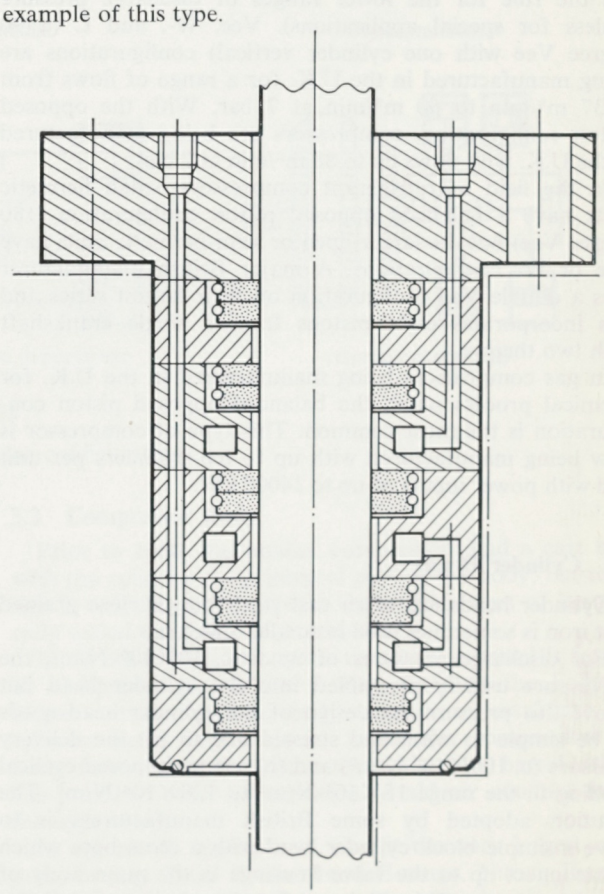


FIG. 14

Five set piston rod pressure seal.
(Courtesy of Mr. R. S. Wilson.)

Various types of linear motion seals in compressors have been used and the figure shows a patented tangent cut seal design. The design of these seals is quite important especially if oil free operation is desired. There have been designs which have used as many as six sets of scraping edges with cooling but these deep packing boxes are now losing their popularity, as the present trend being towards utilisation of just one pair of scraper rings for oil control as shown in the figure. However, multiple sets of packing rings are used to provide the gas seal and a five packing ring set configuration is shown with two bleed-offs in a removable gland (Fig. 14). These packing sets are usually non-metallic and non-lubricated.

The first costs of a compressor with a labyrinth sealed piston are relatively high (*see* art. 2.2.1). Hence this design is comparatively unpopular: mechanical contact rings have proved to be cheaper to manufacture and install.

3.9 Pistons and Piston Rings

Pistons of cast iron and of aluminium are both widely used. Piston ring materials vary widely with service. Common materials for oil free duties are carbon or poly tetrafluoroethylene (P.T.F.E.). In lubricated cylinders, cast iron rings are usually used.

Since the biggest hazard in a compressed air system is caused by the oxidisation of the lubricating oil in the compressed air passages, one solution being increasingly used is to run oil free compressors.

P.T.F.E. has been used as piston ring material even up to pressures of 6000 psi (422 bar) with metallic backing rings and oil lubrication, and also in cryogenic machines to temperatures of −180°F. The current limits of use of P.T.F.E. can be summarised as:

1. Surface temperatures of up to 150°C (average).
2. Sliding speeds of up to 5 m/s.

In high pressure applications, the piston rings are spring backed metallic segments, though P.T.F.E. rings have been tried. Piston ring material is the subject of much current research, filled P.T.F.E. being one of the important materials on which research is progressing at Cambridge University and elsewhere.

The sketches in Fig. 15 show some current designs of piston rings.

In extreme high pressure applications more exotic materials are used for pistons, such as solid tungsten carbide which tends to be weak in tension and hence cannot endure bending stresses without the danger of fracture. At the Symposium on Safety in High Pressure Polyethylene Plants (St. Louis, Mo., U.S.A., May 21—24 1972) many such cases of failure were quoted and very exact alignment is required of the piston in the cylinder. One solution is by adjusting the crosshead in the guide.

Other solutions are a hydraulic transmission with a diaphragm which is one that can be used for extreme high pressures, and a cylindrical crosshead and guide on a common centre line to the cylinder, which is substantially the approach followed by British designers.

3.10 Connecting Rod

The connecting rod is usually a steel forging, attached by a gudgeon pin to the crosshead or piston. The bottom end bearings are usually thin shell bearings except in the smaller sizes of compressor. In the largest size of high pressure compressor the top end bearing is a split thin shell bearing. In such a construction this bearing is the most highly loaded bearing in the compressor.

3.11 Valves

"Automatic" valves are almost universally used. There is a profusion of designs but some form of the annular disc valve is most common. In large compressors, a valve with multiple spring loaded poppets has been used but this has not been a popular design. The importance of surface finish in these valves is extremely important and fully machined valve plates are specified by most users of large compressors. However, they reiterate the problem of obtaining fully machined valve plates and mention that stamped valve plates are still quite commonly supplied by valve manufacturers.

Valves are critical for compressor performance and reliability. The technique of mathematical modelling is leading to a better understanding of valve behaviour. Most manufacturers are now aware of this technique which also allows the influence of piping and intercoolers on the overall behaviour of the compressor and its valves to be studied.

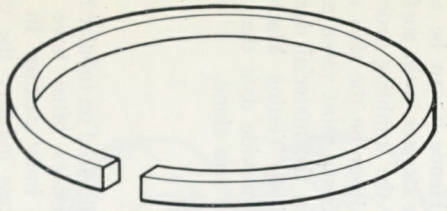
In the gas compressors used in chemical process industry, for the manufacture of low density polyethylene, there are a large number of compressors with spring loaded poppet valves, this type of valve being favoured because of the large straight through gas passage when open, as the blocking of the delivery ducts and valves by low polymers, has been the cause of accidents. Particular caution in the valve design of these compressors is required.

The need for good housekeeping in the assembly of valves cannot be overstressed. This author is of the opinion that precautions should be taken at the design stage to make certain that misassembly is not possible of the valves or of the valve sub-assemblies into the compressor body. It has been stated that manufacturing techniques and gas velocities through the valve are the important factors relating to valve failure.

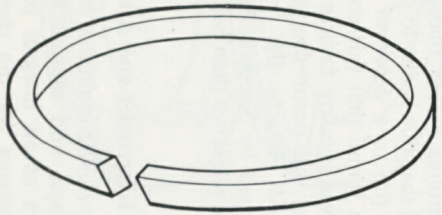
The most common material for valve plates is silicon steel and the most usual mode of failure is caused by impact fatigue. The materials have been the subject of research at the Steel Research Centre of Sandvik A.B. in Sweden, where the effects of composition, tensile strength, surface condition and temperature on their impact fatigue strength were studied. It was found that the most important parameter was surface finish and that the impact fatigue strength increased as surface finish is improved. This effect is further enhanced if valve plate materials are finished by tumbling rather than grinding. Hence it can be concluded that this is due to compressive stresses in the surface layers (up to a depth of 10μm) by the tumbling process. It was found that this compressive layer on the skin also improves bending fatigue strength. Since most valve plate failures still occur due to fatigue in the material due to repeated impacts, the Impact Fatigue Testing Machine developed by Sandvik A.B. should provide data that has greater relevance than bending fatigue data alone.

3.12 Intercooler and Aftercoolers

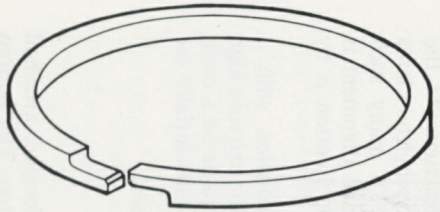
There are a multitude of designs all based on tubular heat exchange, and marine air compressors often have the coolers as an integral part of the body casting. In gas compressors for the chemical process industry the compressors and heat exchanger are usually separate, but are normally offered as a complete package, with compressors and heat exchanger(s) mounted on the same skid.



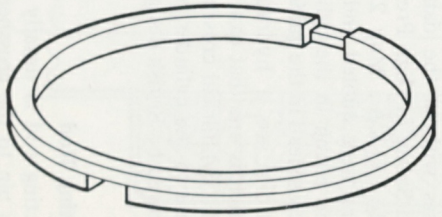
(a) Butt joint



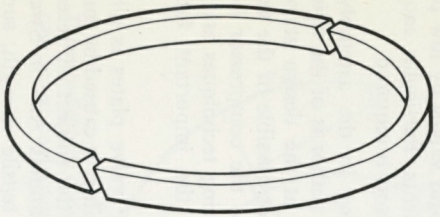
(b) Angle joint



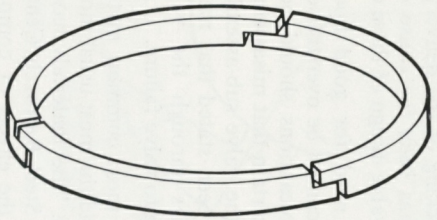
(c) Step joint



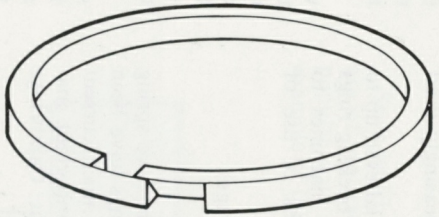
(d) Twinring R



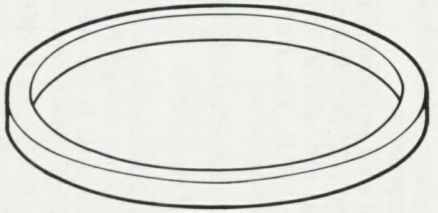
(e) Two-segment



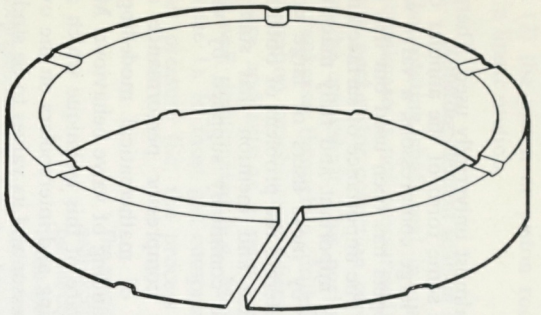
(f) Three-segment



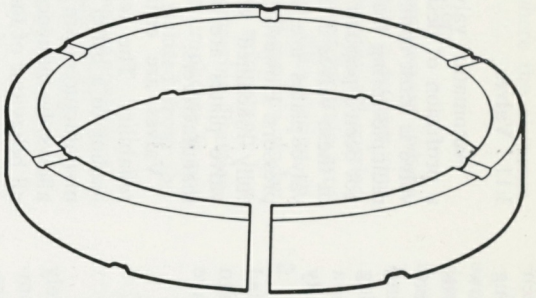
(g) Seal joint



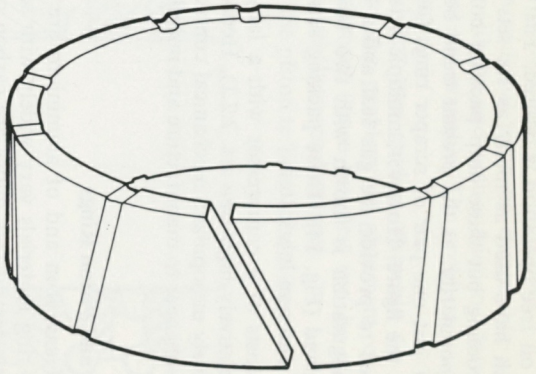
(h) Uncut



(i) Angle joint



(j) Butt joint



(k)

FIG. 15

Piston ring configurations.
(Courtesy of Mr. R. S. Wilson.)

3.13 Drive Mechanism

Various types of drive mechanisms have been used. Fig. 16 shows seven different types of mechanically linked drive mechanisms. Hydraulically driven compressors have the disadvantage of introducing a large number of moving parts into the drive train but have the advantage that by using a diaphragm it is possible to isolate the process gas and so achieve oil free discharge much more simply (i.e. without P.T.F.E. piston rings, extra long piston rods etc.). With a hydraulic drive, it is possible to negate the effects of any leakage at the plunger seal by using the crankcase oil as a transmission fluid. Where diaphragms are used the puncture of the diaphragm at both ends of the compression cycle (the suction pressure of the gas being large enough to cause rupture) is a major problem.

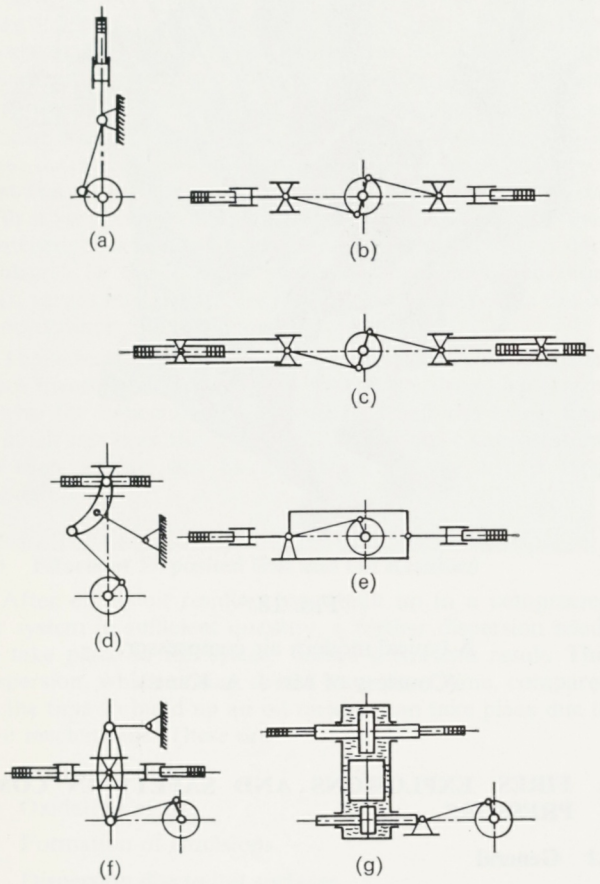


FIG. 16

Piston drive mechanisms.

3.14 Lubrication Systems

Most compressors currently made in the U.K. have some form of forced lubrication for their crankshaft bearings. The oil pump is usually a gear pump driven from the main crankshaft. In the majority of compressors the cylinder lubrication is by splash from the crankshaft, while the gudgeon pin lubrication is part of the forced lubrication system. In the higher range of gas delivery pressure, cylinder lubrication is by high pressure direct oil injection into the cylinder if the process requirements permit.

3.15 Acoustic Enclosures

Modern designs of compressors have to satisfy the requirements of the Health and Safety at Work Act (1974) which specifies a noise limit of 90 dB (A) at the maximum for an exposure of eight hours per day. User specifications tend to be stricter than this if multi-compressor installations have to be provided. Most users specify ISO 85 or ISO 80 noise rating curves as their limit.

Manufacturers have responded to these requirements by (a) reducing noise and vibration generated by the compressor and (b) enclosing the compressor in an acoustically suppressing chamber. Such acoustic enclosures for compressors have been described in literature and most of them use foam, with fire resistant properties (usually to B.S. 476), clad onto steel sheeting or glass reinforced plastic. There have been attempts also to improve the low frequency noise transmission and one method tried has been to mount the compressor on resin chocks. One manufacturer claims a noise level of only 70 dB (A) at 1 m from the surface of an acoustic enclosure containing a reciprocating compressor delivering 121 m^3/hr air at 310 bar.

3.16 Capacity Control

Most compressor plants are required to meet a varying demand, hence there is a need for some form of compressor capacity control. The easiest method is to recycle the gas from the delivery to the suction side. This produces high discharge temperatures and uneconomic operation. Modern capacity control systems usually employ one of the following methods:

(a) Variation in the speed of the prime mover.

(b) On-off operation of the prime mover.

(c) Unloading of the compressor by holding the suction valve open.

(d) Variation of volume of the clearance space in the cylinder.

Throttling of the suction line has been used as a method of capacity control, but this is not used by U.K. manufacturers. It has been demonstrated by the use of the "line pressure diagram", that this method can lead to dangerous conditions and result in either severe overload or stall of the compressor.

The mechanism of capacity control can be considered in relation to the working fluids as follows:

3.16.1 Capacity control for air compression equipment

In air compression equipment, where the fluid is in continuous use and there is only a comparatively small air receiver, methods (a) and (b) above are used. In portable air compressors driven by a petrol or diesel engine, a combination of speed control (a 30% speed variation is possible with the diesel engine) and method (c) is used. This allows the compressor to run continuously. Where electric motors are used as prime movers, method (a) is seldom employed but methods (b), (c) and (d) or combinations of them are used. Stop-start control is particularly useful in smaller plants where demand fluctuates widely (e.g. vehicle garages). Where fluctuations of demand are severe fairly large receivers are used. One manufacturer utilises this system of stop-start control even on large compressors (59.5 m^3/min): either unloading the suction valves or stop-start control can be selected using a selector switch.

The use of variable cylinder clearance is thermodynamically the most attractive method as the energy spent in compression is recovered by re-expansion and the prime mover can be run at constant speed. The disadvantage of

this method is that it increases the complexity of the machine. Nevertheless it is used in compressors which operate at high discharge pressures and hence have a large specific energy input. Use of this method combined with multi-step unloading of suction valves can give stepless capacity control over the entire range of output.

3.16.2 Capacity control for refrigerant compressors

Stop-start control is used almost universally in the smaller range of compressor. In large compressors multi-step unloading of suction valves is the most common method. The fluid used to operate the unloaders is usually lubricating oil. Since the suction valves are part of a liner sub-assembly, the unloaders have also to be part of the sub-assembly.

3.16.3 Capacity control for gas compressors in the chemi-process industry

Methods (a), (c) and (d) are used in compressors for this duty. Method (a) is frequently used in gas engine driven compressors, whilst methods (c) and (d) are most commonly used when employing other prime movers.

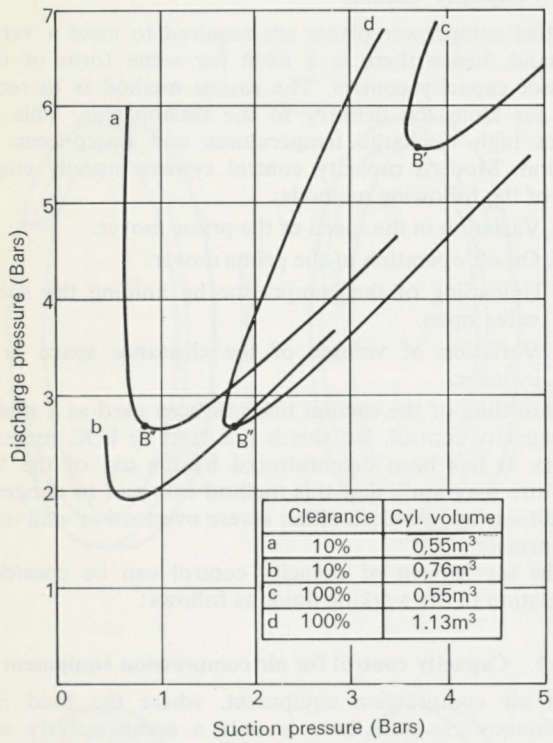


FIG. 17

Effect of varying clearance volume on performance.

3.16.4 Method of selection of type of capacity control

In the smaller sizes of electrically driven compressor it is cheapest and easiest to install stop-start control. On larger sizes of compressor stop-start control may be combined with unloading by opening the suction valves during start-up. Selection becomes complicated in those applications where stop-start type of control would lead to unacceptably high starting loads or where the process requirements are such that continuous stepless (or multi-stepped) control is needed. Sample characteristic curves of variation of discharge pressure with suction pressure at different clearances volumes for reciprocating compressors with variable clearance volumes and with fixed clearance volumes are shown in Fig. 17. These show how the discharge pressure shifts in relation to the clearance volume. With these curves and the "line-pressure diagram" a decision can be made on whether the compressor will meet the required duty.

The techniques to control capacity may soon be considerably improved in relation to system capabilty, system reliability, flexibility and cost by the application of microprocessors.

A typical modern air compressor is shown in Fig. 18.

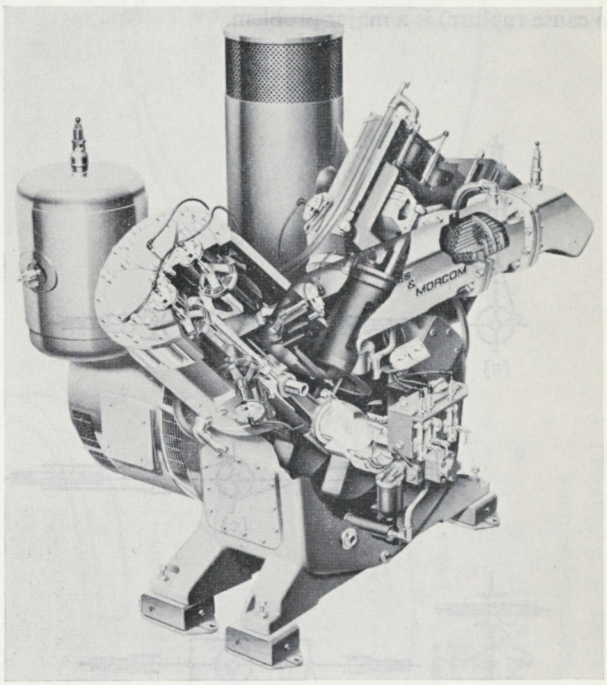


FIG. 18

A typical modern air compressor.
(Courtesy of Mr. J. A. Kane.)

4. FIRES, EXPLOSIONS AND SAFETY IN COMPRESSORS

4.1 General

Fires and explosions have three necessary ingredients—a combustible material, a supporter of combustion and a high enough temperature to provide ignition. The control of fires and explosions therefore implies ensuring that the three ingredients do not come together at one time.

If a combustible gas is being compressed (e.g. hydrocarbons) an exclusion of all oxygen from the process is sufficient, whilst if the gas is non-combustible (e.g. freon) there is no particular problem. When the gas being compressed is a supporter of combustion, problems arise since it may not be possible to exclude combustible materials (e.g. system lubricants) from the combustion process. The majority of fires and explosions occur in air compression plants. Other types of plant at risk are gas compression plants in the chemical process industry, which operate at high pressures (500 bar), where piping may fail due to vibrations and expose gases to an atmosphere containing a supporter of combustion.

4.2 Origins of Combustible Material in air Compression Plants.

The major combustible material in a compressed air system is the lubricating oil. When explosions occur, solid or liquid oil residues are found near the ruptured pipes. Combustible materials may also build up in a system where there is a high concentration of hydrocarbons in the intake air.

The lubrication of the cylinder needs accurately metered quantities of lubricant to be supplied to the walls and piston rings. In trunk piston compressors with splash lubrication this metering is achieved by the use of oil control and scraper rings, whilst in crosshead compressors a direct injection of oil is used. This oil can burn or explode if it is present in a critical quantity. A study of such oil concentration, determined that with traditional compressor oils a lower limit of 48.6 g/m^3 applies. The rate of oil feed is normally significantly below this figure (c. 0.12 g/m^3) even if oil was entrained in the intake air this figure could only increase by a maximum of 0.3 g/m^3. Hence there needs to be a *build up* of oil and/or oil residues in the delivery system before the lower ignition limit is reached.

If we consider the effect of temporary operating conditions where oil input could be greater relative to the air flow, no exact quantative data is available, but it is claimed that the effect is particularly intense if the machine is run with a very low throughput of air for some time and then switched back to full load operation. The oil which concentrates in the cylinder and delivery plenum chamber then surges into the air discharge line and may raise the oil concentration above the lower explosion limit.

The effects of drop size on combustion characteristics were investigated. It was seen that if the drop size is very coarse the concentration needed to reach the lower limit is much less than that required for oil mist. Concentrations of even 3 g/m^3 can be dangerous if drop size is large enough.

4.3 Effects of Deposited Oils and Oil Residues

After oil or oil residues have built up in a compressed air system in sufficient quantity, a further dispersion needs to take place in the system before a fire can result. This dispersion, which occurs over a very short time, compared to the time to build up an oil residue, can take place due to five mechanisms. These are:

1. Creeping of oil.
2. Oxidation of oil.
3. Formation of emulsions.
4. Dispersion due to hot surfaces.
5. Evaporation due to hot air.

4.3.1 Creeping of oil

If a thick oil film of low velocity is deposited on a surface, a turbulent current of air can detach and disperse it. This effect occurs particularly at sharp edges and changes in pipe diameter. Shock waves caused by sudden opening of a valve can also be a cause.

4.3.2 Oxidation of oil

Oil oxidises in the presence of hot compressed air. The oxidised oil contains products which have a higher vapour pressure than the original oil. Ebullition of the high vapour pressure fractions can increase the concentration of combustible material in the air stream.

4.3.3 Formation of emulsions

High oil concentrations can occur in the air stream when emulsions form. These emulsions materialise when the moisture in the compressed air condenses and mixes with residual oil, usually when temperatures are low (e.g. system operation on low load or when shut down). This emulsion is stabilised by rust or dust. When the system is on full load again and the temperature exceeds the boiling point of water there is a spattering of the emulsion and oil drops are thrown into the air stream. This drop size is large.

4.3.4 Dispersion due to hot surfaces

During operation of the compressor on low load the oil film may move onto surfaces which attain higher temperatures during full load operation. Hence, on the compressor being switched onto full load operation, this oil may evaporate and the vapour flow with the air stream. This vapour can pose a danger for considerable distances from the compressor, as the vapour could condense onto nuclei of water vapour and be redispersed by the mechanism described in art. 4.3.3.

4.3.5 Evaporation due to hot air

This effect is similar to that described in art. 4.3.4 and can be particularly dangerous if the air temperature rises excessively due to inadequate cooling, faulty valves etc. The temperature in some cases may be sufficiently high to ignite the combustible material.

The formation of oxidation products is the major dangerous effect and incorporation of mechanisms to transport and deposit oil quickly through the hot zones into colder zones is recommended as well as the use of a vertical air cooler so designed that oil can be cooled and drained off, at suitable intervals to prevent excessive oil build up in the system. It has also been stated that of the oxidation products formed, coke is a major hazard and that a safe limit for the thickness of coke would be 3 mm up to 10 bar and 2 mm up to 20 bar. Where fires have occurred, fracture of the system has only taken place when coke has been present.

Fowle contends that most of the above effects occur in compressors which are on light loads for long periods. Hence, the basic cause is overlubrication during running at light load followed by sudden increases in throughput of air leading to oil dispersion. Fowle is not convinced of the value of draining away the liquid residues because any coke formed is then dry and easily penetrated by the oxygen necessary for combustion.

One other effect of some importance is the insulating effect of the coke or oil residues deposited on the inside surface of the system. Since, in most of the system, heat is transferred by conduction to the outside surfaces, this deposit reduces heat transfer and increases internal temperatures.

4.4 Sources of Ignition in Compressor Systems

The primary sources of ignition in a compressor system are:

1. Sparks within the cylinder.
2. Hot metal surfaces.
3. Auto oxidation of the deposits.

After rupture of the system secondary ignition can occur by,

4. Static electric discharge produced by air containing oil issuing from the rupture.
5. Shock wave impact on deposits.

4.4.1 **Sparks**

Sparks cool very quickly in the compressed air stream. For ignition to occur, a temperature of at least 1000°C is required on the surface of the particle and this temperature cannot be sustained for long. Hence this source of ignition is possible only in the zones close to the discharge outlets from the cylinder.

4.4.2 **Hot metal surfaces**

The temperature needed to ignite an oil-air mixture from a hot surface has no specific value: the work of Thoenes has shown that this temperature varies with the shape, size and material of the hot surface. The evidence of Martinege and Wagner can be cited who determined that a temperature of at least 250°C is needed for ignition. However, degradation of the oil and the catalytic effects of dust and iron oxides can substantially lower the temperature. Various authorities consider that by limiting the maximum allowable air temperature to 140°C in compressed air systems, ignition from the source can be avoided.

It is of interest to note that 50% of fires start as a result of failure of the cooling system in aftercoolers.

4.4.3 **Auto oxidation of deposits**

The auto oxidation properties of coke residues in compressed air systems have been investigated and the results show that there are temperature thresholds at which particular catalysed mixtures of deposits can start a self-sustaining exothermic reaction. This threshold temperature can be as low as 137°C when catalysed by ferric oxide, Fe_2O_3. This is a particularly troublesome catalyst since ferric oxide is a constituent of rust. If the velocity of the air stream is low enough, heat will build up after the reaction has started (i.e. the primary coolant is the air flow) and this will cause the remainder of the (uncatalysed) deposit to ignite.

4.4.4 **Static electric discharge**

The primary rupture can be caused by explosion or by detonation. The passage of high pressure air past the rupture could cause static electric discharge and so provide a secondary source of ignition. However, many ruptures are caused by plastic deformation of over-heated metal and static electric discharge is probably unlikely in such cases.

4.4.5 **Shock wave impact on deposits**

This is a major mechanism of ignition of secondary explosions, and when the system contains even a small deposit of oil and rust, a shock wave can initiate an explosion. Hence damage due to explosions thus initiated can take place at widely separated points along the system. There can be such explosions even without the catalytic effect of rust, if oil film thickness exceeds 0.05 mm on the pipe wall.

After the combustible material has been introduced in the system it would be difficult to eliminate the possibility of fire and explosion because of the several possible mechanisms of ignition mentioned above. Hence preventative measures should be aimed at elimination of combustible products entering and/or building up in the system.

4.5 **Safety Aspects in the Selection of Air Compressor Lubricants**

One approach to reducing the risk of fires and explosions is to develop safer lubricants. Thoenes studied the behaviour of various oils under service conditions and decided that the Conradson or Ramsbottom tests were of no value in predicting the coke producing property of the oil under service conditions. To examine this carbon forming tendency under service conditions Thoenes headed a committee which developed the PNEUROP oil test (POT). This test is now used as a German Standard (DIN 51506 and DIN 51532) for selection of lubricants for air compressors.

A synthetic lubricant which would give safe operating properties and satisfy all the requirements of the POT has been developed. With this type of oil the carbon deposits formed have been found greatly reduced, leading to safer operation.

For safer operation reciprocating compressor oils should:

1. Not allow carbonaceous deposits or lacquer to form.
2. Not readily emulsify with water.
3. Give little or no wear on sliding or rotating surfaces.
4. Not allow corrosion of metal surfaces.
5. Be volatile.

Of the above requirements, the last is debatable since the work of Thoenes shows that volatility per se does not constitute an important parameter. It is the rate of formation of deposit that is important and if the oil is not volatile then the air flow rate can be kept high (*see* 4.3.5.) to ensure that the oil does not dwell in the hot zones.

4.6 **Prevention Measures to Reduce the Incidence of Fires and Explosions in Air Compressors**

Reports on explosions in mineshaft compressed air system, show that cleaning of compressed air systems (which is required by South African mine regulations) is usually done only as far as the receiver, since this was all that was expressly required. In one system the discharge pipe from the receiver to the mineshaft exploded showing that the entire piping system is vulnerable.

It has been recommended that pipework should be installed with inclinations such that no major deposits can form in pockets and that all low level points be provided with a drain. Air speeds should be at least 8 m/s through the system to prevent any build up of oil on pipe surfaces.

A suggestion which could increase the intervals between cleanings without increasing the fire risk, is the addition of 5% triaryl phosphate to the lubricant. The object of this additive is to fireproof any coke deposited in the system.

As mentioned earlier one of the major contributory factors to fires is inadequate design of aftercoolers. A vertical design of an aftercooler has been used in some installations and such a cooler, with small diameter tubes, could be dimensioned to act as a pulsation damper, and so eliminate separate dampers where oil could collect.

Thoenes considers the matter of oil separators on the discharge side and recommends that those which conform to the present German regulations are the safest. It has been suggested that incorrect location of these separators can be an additional hazard due to oil collecting in them. If separators are fitted with close mesh filtering media which collect oil, the safe upper limit of operating temperature is 40°C.

One other approach is to consider that the problem of fires is endemic and that in traditional compressed air systems the hazard cannot be entirely eliminated. Following this philosophy one recommendation was the quench system in the delivery pipeline. Such a system is shown diagrammatically in the sketch. (Fig. 19).

It has been claimed that this system limits the working temperature of the compressed air and provides a fluid film which accelerates oil creepage, thus reducing oil dwell time in the hot zones. Since the air is saturated with water vapour the problem of boil off from the emulsion (art.

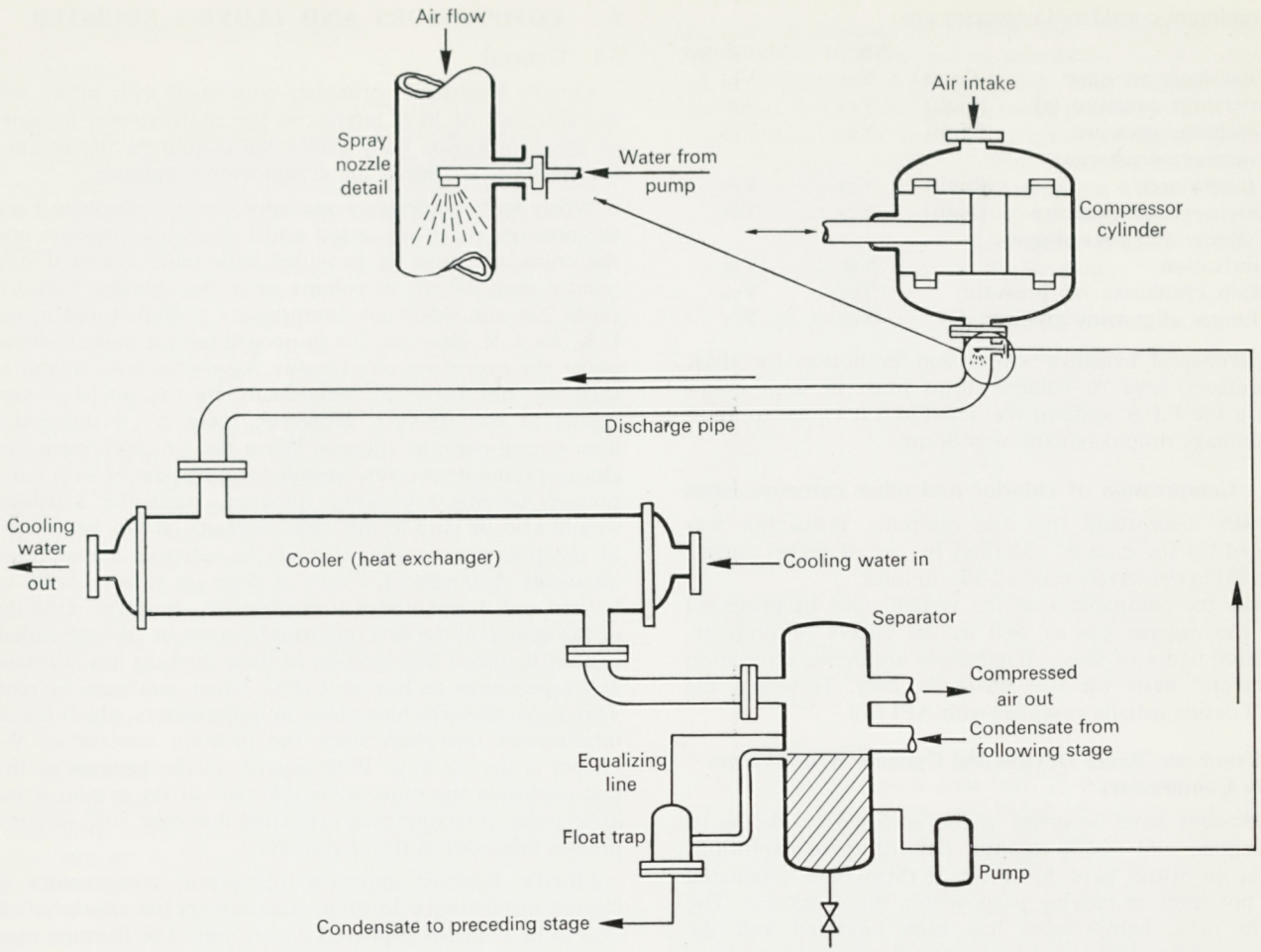


FIG. 19

Water quench system for air compressors.

4.3.3) is also eliminated. There is then a need for an efficient separator, since any carry-over of liquid water into the next stage can have harmful effects.

A similar recommendation that steam be injected into the discharge air stream to assist in oil separation has also been made, but the cheapest method of removal of oil is by using a vertical aftercooler. Aftercoolers have been expressly designed for this purpose.

Another solution to the problems arising from combustible material being entrained in the intake is catalytic oxidation on the suction side. This does not eliminate the problem entirely and a liquid wash may be required on the discharge side. Catalytic oxidation followed by cooling and final scrubbing (either interstage or at the end of the compression process) is the accepted method of treatment at present in large capacity air compression plants.

The most effective method of achieving particle removal is by water scrubbing.

4.7 Safety in Process Gas Compressors in the Chemical Process Industry

A different situation from air compression plants has to be provided for here. The process gas may be combustible but not a supporter of combustion. Flammable process gas should not come into contact with atmospheric air on high pressure processes such as manufacture of ammonia or low density polyethylene.

4.7.1 Ammonia and hydrogen compression plants

The reactivity of compressed hydrogen is so great that all relief valves etc., in compressed hydrogen plants have to be blanketed by injection of an inert gas (usually nitrogen) in case fires start. Mercury must be completely removed from all process gas as it causes embrittlement of admiralty brass tubes in intercoolers and aftercoolers. There are also cases on record of catalytic dissociation of ammonia by mercury and subsequent explosion. Rock wool is used to prevent flame propagation in pipelines and it is contended that this method of flame control is applicable even when hydrocarbon mixtures are being compressed.

4.7.2. L.D.P.E. Plants

The highest pressures normally found in gas compression are encountered in L.D.P.E. synthesis plants. Here the compressor components are themselves at risk due to high loading. Safety in this type of compressor requires that the calculated and actual loadings correspond and act in the directions envisaged. Failures in these compressors have occurred due to eccentric loading, high cyclic stress producing fatigue, etc. Since the gas being compressed is highly combustible the consequences of a failure are disastrous. Alarms and shutdowns are to be incorporated into these very high pressure systems to ensure safe operation.

The minimum considered necessary are :

		Alarm	Shutdown
1. First stage pressure	(low)	Yes	Yes
2. Interstage pressure (s)	(high)	Yes	No
3. Discharge pressure	(high)	Yes	Yes
4. Interstage discharge temperatures	(high)	Yes	Yes
5. Discharge temperature	(high)	Yes	Yes
6. Cylinder and yoke slipper lubrication		Yes	Yes
7. Main crankcase oil pressure		Yes	Yes
8. Plunger alignment monitor		Yes	Yes

Experimental evidence shows that in houses for these compressors, area to volume ratios must be kept below 1:15 (in the F.P.S. system) (i.e. 1:4.6 in S.I. Units) to minimise damage should an explosion occur.

4.7.3. **Compression of chlorine and other corrosive gases**

It was determined that the optimum protection was obtained (in the case of chlorine) by use of nickel plating deposited in two layers each 12-15μ m thick.

Hence the components of the system must be protected from the process gas as well as the effects of pressure. Therefore many of these compressors are manufactured on a "one-off" basis for the particular duty. However, the overall design usually complies with API 618.

4.8 Crankcase Relief Devices and Cylinder Relief Valves in Compressors

Explosions have occurred in the enclosed crankcase of I.C. engines and steam engines. Few of these explosions are due to piston blow by: most of them have originated from hot spots in moving parts within the crankcase. The risk in these compressors has been analysed and the risk is considered to be of the order of one incident every 420 years of operation, though the risk may appear low it is still unacceptably high in process plant and the usual policy is to fit a crankcase explosion relief device with a relief area 3 in^2/ft^3 (560 cm^2/m^3) of crankcase volume.

Lloyd's Rules require relief valves on compressors which provide air for starting main engines, when compressor crankcase volumes exceed 0.6 m^3. These explosion relief devices require a relief area of 115 cm^2/m^3 of crankcase volume with a minimum area of 45 cm^2 per valve. The Rules also require relief valves if the cylinder bore exceeds 200 mm.

Relief valves for compressor cylinders are normally designed so that when running the compressor at full capacity with the discharge valve closed and all gas being discharged through the relief valves, the pressure in the cylinder does not exceed 110% of rated pressure. This test is known as the "accumulation of pressure test" and the requirements are normally referred to in specifications, by the excess of pressure over the rated pressure (e.g. maximum accumulation of 10%). The commonly used material for relief valves for air compressors is brass or cast iron. These materials are usually not acceptable for relief valves on process gas compressors (API Specification 618).

If the compressor is water cooled, relief valves are usually provided on the water jacket to prevent undue pressure in the jacket due to any rupture of the internal pressure parts.

Lloyd's Rules, require fusible plugs or an alarm device which operates at 121°C to be provided on each compressor. (Part 5, Chapter 2, Section 8.)

5. COMPRESSORS AND LLOYD'S REGISTER

5.1 General

Lloyd's Register is primarily concerned with safety and therefore we do have interest in the contructional integrity of the compressor body under the conditions of dynamic loading imposed when the compressor is running.

When any compressors are approved for shipboard use the pressure parts are tested under hydraulic pressure and the crankcase must be provided with relief valves if it is greater than 0.6 m^3 in volume or if the cylinder bore exceeds 200 mm. Most air compressors manufactured in the U.K. for L.R. class and for shipboard use are manufactured under the manufacturers Quality Assurance scheme and as such are not surveyed individually by the Society's surveyors at manufacture. However, these are a surveyable item during periodic surveys. When the air compressor discharge piping or pressure vessels forming part of such compressor systems are being surveyed, particular attention should also be paid to any coke deposits on the inner walls of the pressure system. A guide to safety is a maximum allowable thickness of 3 mm of coke up to a pressure of 10 bar and 2 mm above that pressure—however, cleaning of the system at the first opportunity must be recommended. It must be noted that ignition of these deposits has occurred at temperatures as low as 137°C, when catalysed by rust. This is particularly hazardous in compressors which are in intermittent operation since the primary coolant of the system is the air flow. With regards to the hazards of fire and explosion the most vunerable part of the system is the aftercooler, it having been estimated that over 50% of compressor fires start in the aftercooler.

Lloyd's Register approves refrigerant compressors in classed installations. In these compressors the crankshaft is also to be made to approved dimensions. The formula used for this rule size is quite different from that used in engine crankshaft approval.

Most compressors are given general approval since they are mass produced to a limited number of designs and by a limited number of firms. However, most refrigerant compressors intended for classed marine installations and cold stores are individually inspected and tested during construction in accordance with the Society's normal survey procedures. Of course, some compressors are one off installations and these are individually considered and inspected under construction for an installation which will receive the ✠. The mass produced compressors are usually approved to Lloyd's Register Quality Assurance scheme for batch produced machinery.

Design of refrigerant compressors is now reaching its limit (keeping economy in mind) and is in quite an advanced stage of development.

In this the various advantages that refrigerant compressors enjoy over other compressors generally, and air compressors in particular, must be mentioned—these are:

1. The gases handled are moisture free and clean.
2. The majority of gasses used are not combustible or supporters of combustion.

With refrigerant compressors it is the Society's practice to keep the dismantling of these compressors to a minimum consistent with reliable performance and, over the years, the intervals between dismantling have been extended but complete dismantling of reciprocating compressors is still required at intervals not exceeding 4 years.

6. CONCLUDING REMARKS

6.1 General

The present range of delivery pressure and capacity of reciprocating compressors is up to 8000 bar and 10^4 m^3/h respectively. Within this range it faces competition from centrifugal compressors at pressures up to 600 bar when flow rates are over 7 x 10^3 m^3/h and from screw compressors at pressures up to 60 bar when flow rates are over 500 m^3/h. The major advantage of the reciprocating compressor is its high efficiency. This efficiency decreases with increasing number of stages, even with intercooling. This loss of efficiency makes it less competitive than rotary compressors where higher pressures and large flow rates are involved. The major disadvantages of the reciprocating compressor are the higher capital costs and the relatively large floor area required. An item by item comparison of advantages and disadvantages of reciprocating compressors shows that, overall, they are competitive in applications up to the flow rate mentioned of 10^4 m^3/h.

There are special conditions which dictate the use of design of reciprocating compressor particularly developed for these applications. The most widely used of these are the diaphragm type compressor and the hermetically sealed refrigerant compressor. The diaphragm compressor can only be used at low flow rates but it can be used at very high pressures if the diaphragm is hydraulically actuated.

6.2 Reliability in Compressors

Users in the U.K. are of the opinion that reciprocating compressor reliability should be improved and that this improvement should be the first priority in the research and development programme of manufacturers. However, the cost effectiveness of the investment needed to achieve improved reliability has not been established.

A statistical study of the reliability of reciprocating compressors gives a curve such that the 97.5% lower confidence limit shows a reliability of at least 9295 hours before failure under the normal industrial conditions met within the U.K. The mean time to repair a compressor breakdown is three hours. The failure rate in hermetically sealed compressors is 2%: these compressors usually carry a five year guarantee. However, the evaluation of reliability is difficult due to the lack of data. Because of this difficulty it is unusual for reliability to be quantified in specifications.

6.3 Standards

American standards are adhered to, at present, in reciprocatng compressor construction but these are vague in some important respects, so necessitating supplementary specification by users. The lack of a British Standard relating to construction is keenly felt. The British Standard specifications deal only with rating and testing of compressors. There is dissatisfaction among users with the British Standards relating to the method of flow measurement recommended at present. Investigations are underway to determine whether the flow measurement technique can be modified.

6.4 Compressor Lubrication

Oils in compressors act as lubricant, coolant and sealant of moving parts. The properties required vary according to whether or not the oil comes into contact with the process gas. If in contact, the oil must be compatible with the gas. Lubricants in contact with refrigerants suffer a reduction in viscosity due to miscibility, i.e. the dissolving of the refrigerant in the lubricant. That refrigerants themselves be used as lubricants presents problems.

In non-lubricated compressor cylinders, the most popular self-lubricating material is filled P.T.F.E., the most commonly used filler being carbon-graphite. Other plastics and organic resins have been tried but with less success. Research is continuing on developing filled P.T.F.E. with better properties to meet particular duties.

6.5 Noise and Vibration in Compressors

Noise and vibration in reciprocating compressors still poses problems. Other countries in the E.E.C. prescribe stricter noise standards than does the U.K., and exporters of compressors must become aware of this. As the U.K. moves into greater integration with Europe, stricter noise legislation can be expected.

Manufacturers consider that reducing noise levels generated by unenclosed compressors below 90 dB(A) will be difficult. Installation of the compressor and construction of the compressor house can be designed to minimise transmitted noise and vibration, but low frequency noise and vibration remain problems as they can be difficult to filter out and are being increasingly recognised as significant health hazards.

6.6 Gas Pulsations

Gas pulsation levels now tend to be higher than in the past due to higher rotational speeds of compressors, greater capacities of plant etc. This increase in pulsation levels increases the incidence of compressor and piping failures and more adequate criteria for pulsation assessment and control need to be developed and applied. The most rational method is to use integrated system design criteria of the type recommended by W. Von Nimitz. However, this type of criteria necessitates the use of analogue or mathematical models and the expense involved can be considerable. The most common pulsation control devices are orifices, expansion resonators and filter resonators. The placement of these devices can lead to problems unless the entire installation has been analysed. Pulsation dampers are frequency sensitive and so may not be effective over the range of operating capabilty of the reciprocating compressor. The effect of such pulsation control devices has been investigated by both analogue and mathematical modelling. Analogue modelling has generally been used for larger compressor systems and mathematical modelling in smaller compressors.

6.7 Fire and Explosions

In compressed air systems fires and explosions occur mostly downstream of the compressor. The combustible material in these incidents has been oil and/or carbon residues accumulating from lubricants. The ignition temperature of such residues can be as low as 137°C when catalysed by rust.

The coke producing qualities of the oil are not adequately predicted by the Conradson or Ramsbottom tests and the PNEUROP oil test (POT) attempts to provide a better guide. Various improvements and preventive measures have been proposed to minimise the occurrence of fires and explosions: the most popular has been the development of safer lubricants and improved aftercooler design.

There is a large amount of development work in progress relating to compressor safety.

ACKNOWLEDGEMENTS

The author wishes to acknowledge his thanks to Prof. J. F. T. Maclaren of the University of Strathclyde for advice in the preparation of this paper.

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. . . and to thank colleagues at Lloyd's Register who have helped in the preparation of this paper—particularly Mr. A. A. Wilson of the Refrigeration Department.

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Discussion

on

Mr. Bharath S. Rajan's Paper

RECIPROCATING COMPRESSORS

Paper No. 5. Session 1979-80

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71 Fenchurch Street, London, EC3M 4BS

Discussion on Mr. Bharath S. Rajan's Paper

RECIPROCATING COMPRESSORS

CONTRIBUTIONS

From Mr. G. P. Smedley:

There is a considerable amount of useful information contained in the paper. For any type of machine the reliability is of vital importance. In part 6.2 of the paper, it is stated that the 97.5% lower confidence limit shows a reliability of 9295 hours before failure of a compressor under normal industrial conditions. It is probable that the mean time to failure would be appreciably greater.

The definition is not given of 'failure' in this context. For example, some years ago I was called urgently to a chemical works where two large ammonia compressors had sustained major damage after a few months of continuous operation following a major overhaul. The two breakdowns had occurred within a very short period of each other. The owner was surprised that the running times to failure were almost identical. During the overhaul the bottom end bolts of both compressors had been renewed. As replacement bolts could not be obtained from the manufacturers, they had been made locally, and unfortunately the threads had been cut with very sharp root radii. Fatigue fractures from these severe stress raisers were the causes of the incidents. From this, and other cases, I have found that fatigue arising from severe stress raisers in identical component parts, can result in a narrow distribution of the time to failure. If the data for such failures were pooled with service experience from machines of similar type, there would be a serious bias on the lower limit of time to failure.

It is advisable to separate running times of new machines from those of overhauled machines. This can indicate faults or oversights in maintenance and replacement. Since wear and fatigue can be dependent on the total number of revolutions, what was the variation of the reciprocating compressors included in the reliability analysis quoted in the paper?

From Mr. D. McKinlay:

I would like to congratulate the Author for producing a most interesting paper in a field in which he has particular knowledge.

This paper is unusual for our transactions as there is a considerable amount of information relating to costs. Costs are important and it is a refreshing change to have information on this aspect.

I was interested to read of methods which have been developed for the impact fatigue testing of valve materials. I have no experience of this test and I would be pleased if the Author could give some details.

The Author is critical on page 6 of British designers, for not incorporating the improvements he mentions. I would not accept that all these points are improvements and I would ask the Author if Continental designers had incorporated these points in their compressors.

Lastly, I would ask the Author to elaborate on the line pressure diagram (Fig. 10) and how curve 'a' in the diagram is constructed?

From Mr. C. Archer:

I must congratulate the Author on an interesting paper which provides a very good introduction to so many topics.

Having read the paper I recounted Technical Investigation Department's experience with reciprocating compressors and found it to be surprisingly small considering the number of machines in service.

Over the past few years we have investigated only two cases, one related to a reduction of a compressor performance and the other where there had been a catastrophic failure.

In addition there have been many vibration investigations in which the reciprocating compressor was identified as the source of excitation. In this context it should be stated that despite some quite considerable secondary unbalanced forces which can be inherent in reciprocating compressors it has been demonstrated that they can run without undue vibration and without massive holding down arrangements. It is the excitation and response or resonant frequencies in the associated plant and pipework which usually results in excessive vibration.

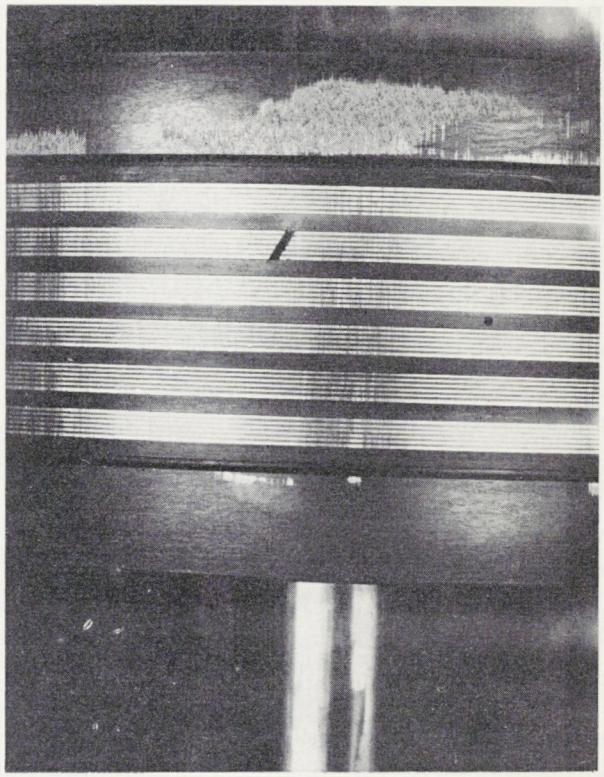

FIG. 1

Excessive wear in a helium compressor with unlubricated bronze piston rings—1.

The case of reduced performance referred to, was that of a four stage, double acting, helium compressor. It transpired that the lack of performance was due to seizure of the rings in their grooves and excessive wear-rate on the outer surfaces of the ring. There was evidence of a great deal of scuffing, as can be seen in figures 1 and 2. The surprising feature was that bronze piston rings were being used without lubrication or cooling and I found it difficult to believe that such a design could possibly be successful. I note that in the paper reference is made to non-metallic

materials, such as P.T.F.E., which would seemingly solve such a problem but I would ask the Author to comment on the possible limitations of such materials.

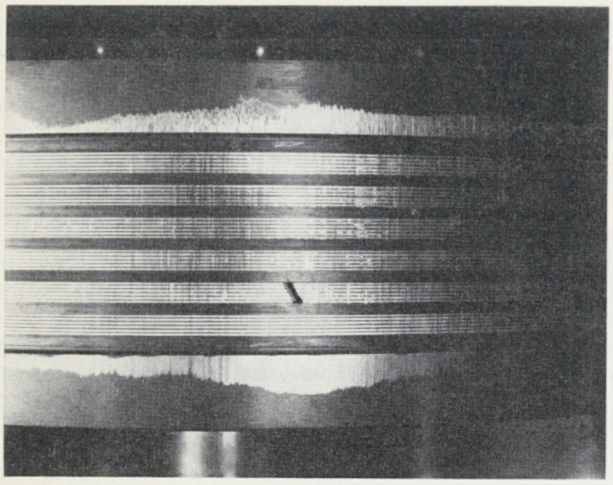

FIG. 2

Excessive wear in a helium compressor with unlubricated bronze piston rings—2.

Section 3.11 refers to impact fatigue properties of steel. Could the Author expand this by commenting on the possible correlation between this property and bending fatigue. Would surface hardening improve the impact fatigue properties.

Regarding the noise and vibrations mentioned in Section 3.15, I notice that one manufacturer claims some benefit by using resin chocks. Could the Author tell us how much improvement he achieved?

Finally, referring to Section 4.2 where fires and explosions are discussed, what is the reason for larger oil drop sizes being more dangerous than smaller drop sizes? This would seem contrary to that normally expected.

From Mr. J. C. Harrison:

I would like to thank Mr. Rajan for an interesting paper on rather a neglected subject.

Together with engines and pumps, compressors are one of the three basic groups of machines. This is illustrated on page 2 of the paper, but the Society's involvement with them is, nonetheless, rather slight. Since the passing of the main propulsion diesel engine with air-blast injection, the compressors to be found in general marine practice are limited to those for starting air, control air and general service. Although starting air compressors are normally two stage, none of these machines can be regarded as very sophisticated and they seem to be viewed rather casually by the Society. Certainly they do not get the attention given to air receivers.

On page 18 of his paper the Author mentions that the formula used for the approval of refrigeration compressor crankshafts is quite different from that used for engine crankshafts. This prompted me to look for the corresponding formula for air compressor crankshafts in Part 5 of the Rules to see how they compared. Rather to my surprise, I find there isn't one. How then do we approve compressor crankshafts? To apply the internal combustion engine formula seems unnecessarily stringent. Further, it appears from the Rules that we have no requirement for torsional vibration analysis for reciprocating compressors. Admittedly the torque diagram is much more uniform than for an engine with the same cylinder configuration but does the evidence suggest that crankshaft failures from this cause never occur? Perhaps manufacturers do their own calculations.

I was very interested to read of the ultra high pressure compressors; a category of machine which I have not only never seen, but which I did not even know existed. Mr. Rajan gives us a tantalizing glimpse of compressors for 8,000 bar with tungsten carbide pistons. This pressure is in excess of 50 tons per square inch which is well beyond the yield stress of many engineering materials. The engineering of compressors for these prodigeous pressures must be very complex and I would be grateful if the Author could enlarge a little on the details of their design and construction.

The paper is entitled 'Reciprocating Compressors', but mention is made of various types of rotary compressors and I hope the Author will not take exception if I mention one of the latter which is not included in the paper but which is currently of considerable interest. This is the Zimmern single screw compressor which has only recently made it's appearance. The mechanism is simple but the continuously altering configuration of the gas passages as the elements rotate is not easy to follow without a sectioned model. Suffice it to say that it gives positive displacement and has the merits of a minimum number of moving parts; the forces are balanced, the output has minimal pressure pulsations and the machine has a good capacity in relation to it's size. It is already in extensive use as a portable air compressor. It also has characteristics which make it eminently suitable for refrigeration work. All major manufacturers of refrigeration compressors have machines of this type on the drawing board or in production and it is to be expected that they will make considerable inroads into the field at present dominated by the reciprocating compressor.

Continuing in the refrigeration sector, the largest reciprocating compressors with which the Society has a classification involvement are those used for the reliquefaction of cargo gases. Here, I think that the Author has been a little cavalier towards labyrinth seals saying that they are not popular at the present time due to their cost. The merit of the labyrinth seal for glands and pistons is that although it demands a higher quality of engineering, it does not require lubrication. In many process industries this is an essential feature as the product being compressed must be free of oil contamination. This is also true of the cargo gases. For this reason labyrinth type compressors by one particular manufacturer are popular to the extent that they have virtually monopolized the market. The reputation of this particular manufacturer is such that notwithstanding the higher first cost compressor of this type are also extensively used for more prosaic refrigeration applications such as skating rinks, etc.

At the other end of the refrigeration scene, I would like to mention the hermetically sealed compressor which has now been more or less universally adopted for domestic equipment. Prior to the introduction of compressors of this type, the majority of failures in domestic machines were due to loss of refrigerant. This problem is entirely overcome by the hermetically sealed compressor, but it is well to bear in mind that any failure of the motor will result in contamination of the refrigerant circuit by hydrocarbons. It may be feasible to open up the compressor/motor container and repair the motor but it is not practicable to decontaminate the system. Thus, a failed motor results in a scrapped unit. For small units this is acceptable but there comes a point in size where the economics no longer allow

this. For this reason we do not see hermetically sealed circuits in anything but small plants.

While speaking of domestic refrigeration units, it is worth mentioning that a particularly interesting small electrodynamic compressor, with a linear motor, is currently under development independantly in both Holland and Japan. Apart from normal leaf type valves, this compressor has only one moving part; the piston. It is conceived as an opposed cylinder configuration with a single free double-ended piston which operates as an armature in a reversing magnetic field excited by a coil. The system is tuned so that the exciting frequency (50Hz) is the same as the resonant frequency of the piston/compressed gas system. The engineering is not as simple as might appear and it is believed that no such compressor is yet available commercially, but it's potential looks very considerable once the development problems are solved.

From Mr. A. A. Wilson:

Do we understand that 'aerodynamic' type compressors mean the same as 'dynamic' as included in the chart on page 1.

On page 2 there is a brief description of early valve development. A few simple sketches published in the written discussion would improve clarity.

Concerning figure 5 on page 4, it is a pity that the comparison is between 2-stage reciprocating compressors rather than two other types, both single-stage, and which both have inherently lower pressure ratios. Does in fact the pressure ratio get taken into account in 'unit capacity', or merely the swept volume?

In paragraph 2.2.2 the sentence "However . . . reduced" does not appear to be sensibly in context. It is surely intended to imply that these compressor configurations are better than *in-line, vertical, reciprocating* layouts.

In paragraph 2.2.3 I was puzzled by the implication that 'floor space' is of low importance in ship's engine rooms, and also by the stated reasoning with cold stores.

Concerning figure 7, does this apply to reciprocating or all types of compressors? On this subject, to my knowledge all *Screw* refrigeration compressors run at 3000/3600 rpm depending on the AC motor frequency. This may have a bearing on paragraph 2.2.5, where running and replacement costs are compared.

Paragraph 2.2.6 hardly applies to refrigerant compressors, especially with reference to stripping to clean out carbon deposits. Refrigeration compressors remain very clean internally.

With reference to paragraphs 2.6 and 2.7, do vibrations and noise of reciprocating compressors cause problems in ship installations? Certainly large screw refrigeration compressors are very noisy and can impart high frequency vibration to a deck.

Concerning the first two sub-paragraphs under 3.2, do these refer to air compressors only?

Concerning paragraph 3.8.1, with reference to the correct statement that 'the crankcase may be used as a reservoir for refrigerant', it should not be supposed that it acts as a 'liquid receiver', which is a component fitted in the liquid-phase part of the refrigerant circuit. Any refrigerant in the compressor should be in the vapour phase!

Concerning paragraph 3.9 we have recently had confirmation from a well-known U.K. refrigeration compressor manufacturer, allowing the random mixing of cast iron and aluminium pistons in one eight-cylinder machine, but the practice is not generally advocated.

With reference to paragraph 3.16, it is concluded that the proposed capacity control systems apply to *reciprocating* compressors.

On page 18, I think the sentence should read: 'Of course, some compressors are one-off *designs* and these . . .'

In conclusion, I think the paper is excellent, and I hope it has proved as interesting to others as it has to me.

AUTHOR'S REPLY

I would thank all those who have contributed to this discussion.

To Mr. Smedley:

In the study quoted in the paper the M.T.B.F. was found to be 15895 hours with the 2.5% upper confidence limit being 29853 hours. Further breakdown by classes was not carried out. It is of relevance to note that the only other study that has been documented in literature is a Russian one (1) which gave an M.T.B.F. of 9615 hours.

To Mr. McKinlay:

Impact fatigue testing was first developed by Dr. M. Svenzon of the Sandvik Steel Research Institute. The machine that he developed consists of a fluidic device which vibrates a flapper made of the material under test against a hardened steel stop. The frequency is maintained at the resonant frequency of the flapper.

A base spring load of 4300 N/m^2 means that this differential must exist before the pressure starts having any effect on the inertia of the moving parts. In modern compressors with disc type 'automatic' valves the base spring load varies with the final discharge pressure, but is in the range 100 to 1000 N/m^2, with the normal air compressor valve with a discharge pressure of 8 bar having a base spring load close to the figure of 100 N/m^2.

In taking issue on the point about improvements, Mr. McKinlay reflects the feeling of British designers that to introduce complexity is to reduce reliability. This is to a great extent borne out by my reply to Mr. Smedley where it is seen that Russian compressors are less reliable by comparison. Unfortunately no other studies of the effectiveness or otherwise of these modifications can be found in literature and hence a quantitative assessment cannot be made.

The curve 'a' in the line-pressure diagram is a constant power curve and this is constructed by considering the compression process as polytropic, giving the well known expression:

$$\text{Power} = \frac{n}{(n-1)} P_s V_s^1 [r^{(n-1)/n} - 1] \frac{e_v}{e_m e_a}$$

Where n = Index of compression
P_s = Suction pressure
V_s^1 = Swept volume
r = Pressure ratio
e_v = Volumetric efficiency
e_a = Adiabatic efficiency

The pendant characteristic is obtained by considering all the parameters as constant except for P_s and r, and then solving for these over the range required.

To Mr. Archer:

Chemical plant experience has shown that Mr. Archer's comment is generally justified in that the major source of compressor plant problems have been due to excessive vibration in the associated pipework which are excited by gas pulsations in the system. This has led to analogue model studies of large capital cost plants being a standard feature of specifications.

Helium does not adversely affect P.T.F.E. and hence the operating limits stated in paragraph 3.9 apply and provided that the helium compressor mentioned was operating within these limits, the use of P.T.F.E. rings in a non-lubricated environment would have been a viable solution.

The impact fatigue properties of valve plate steels seem to have little correlation with their bending fatigue properties. The major influence on the impact fatigue seems to be the surface finish with impact fatigue properties improving with the finish. Surface hardening seems to marginally improve impact fatigue strength but does not have such a decisive influence as surface finish.

On a close check being made of the claims which were made for the attenuation due to resin chocks, I feel that the best that can be said is that the case is *not proven* and at worst there is an increase in transmission of low frequency components. However, there seems to be a subjective opinion among operators that some improvement was achieved.

Finally Prof. Thoenes' research seems to suggest that the major parameter in the ignition of oil droplets is the surface area/mass ratio, the smaller the ratio the greater its heat retention characteristics and hence its inflammability. This seems to be the reason for the larger oil droplets becoming primary sources of ignition more readily.

To Mr. Harrison:

With reference to Mr. Harrison's first point—the answer is that we do not 'approve' compressor crankshafts, we only 'note' them. We calculate the strength of air compressor crankshafts from first principles and apply Von Mises criteria to failure.

Torsional vibration calculations are not required for air compressors and it is quite unusual to be asked for them to be carried out. However, in the larger class of compressor (for chemical process industry applications) these are normally carried out by the manufacturer and some users of these large compressors carry out their own calculations.

The hypercompressor field, that I have described, where compressors have discharge pressures in excess of 1000 bar having large flow rates and absorbing powers up to 34 Mw, are in a decline. This is due to the development of low pressure catalytic processes for L.D.P.E. manufacture. However, the drawing, figure 3, shows the cross-section of one of these magnificient machines and figure 4 a photograph.

The labyrinth piston compressor is, of course, a machine eminently suitable for the type of market Mr. Harrison describes. Present cost accounting in most purchasing departments are optimized over a ten year assumed life of machines and hence the major virtue of this type of machine, its reliability over a long period of time, is masked by its high capital cost leading to a reduction in its use—oil free operation being achieved by use of non-metallic self lubricating materials such as P.T.F.E.

The linear resonant piston compressor was originally invented in 1932 and the system patented then had a spring as part of the resonant system. The problem apart from the control system was that some amount of transverse vibration was also generated by the system which produced contact between piston and cylinder wall.

To Mr. Wilson:

Mr. Wilson infers correctly that dynamic and aerodynamic are identical types.

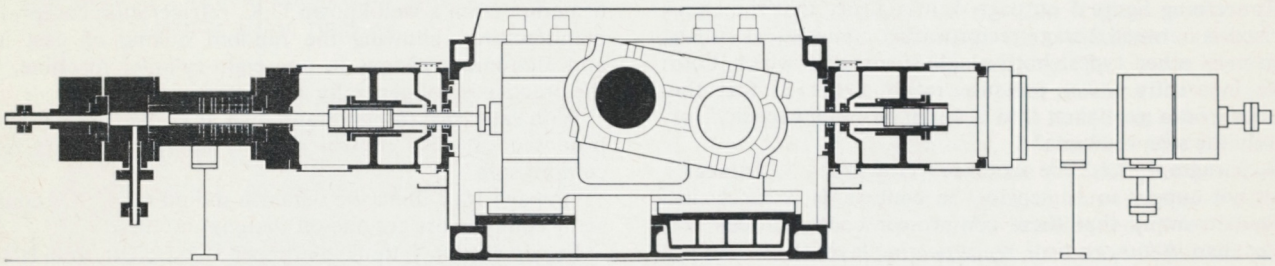

Fig. 3

Cross-section through a hypercompressor.
Courtesy of Sulzer Bros. Ltd.

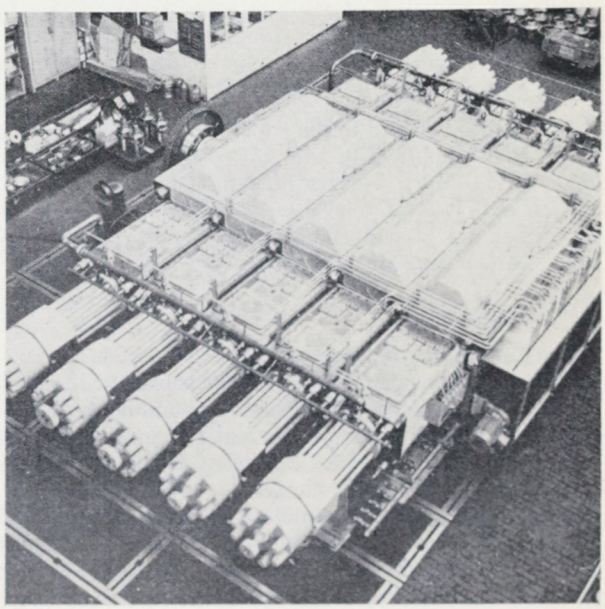

Fig. 4

Hypercompressor for L.D.P.E. manufacture.
Courtesy of Sulzer Bros. Ltd.

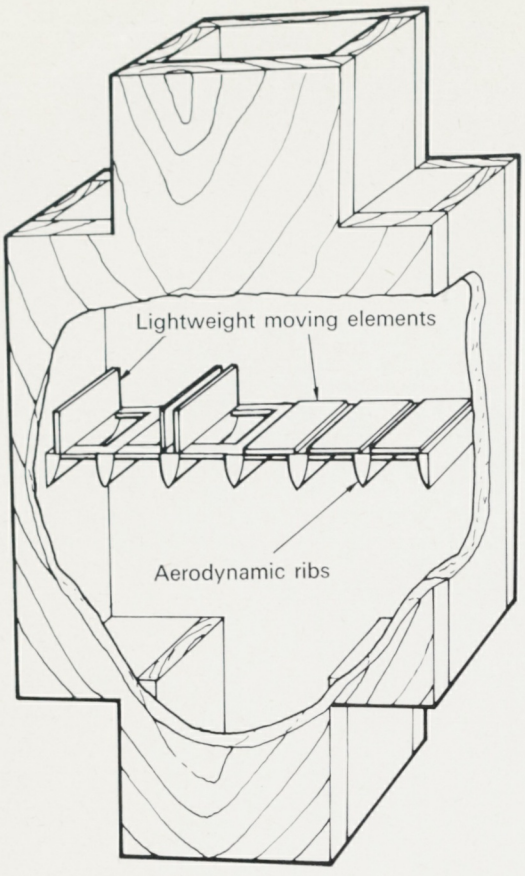

FIG. 5
From an idea by Leonardo da Vinci.

The most important of early valve developments—the Leonardo da Vinci valve—is shown in the accompanying figure 5.

Unit capacity in the graph, figure 5 in the paper, takes into account only swept volume and Mr. Wilson infers correctly that the comparison in paragraph 2.2.2 is a comparison against the in line, vertical configuration.

With reference to Mr. Wilson's comments on paragraph 2.2.3, I intended to make clear the fact that though floor area is an accountable item there may be spare floor area available due to extraneous factors and hence each case should be considered on its merits when dealing with costing this item.

Figure 7 applies to only reciprocating compressors.

Mr. Wilson is quite justified in considering that the sentence on page 18 should read 'of course, some compressors are one-off designs and these . . . etc.'

Reference:

Arslanov N. I., Kats A. G. and Kramer, I. D.: Investigation and Evaluation of Operating Reliability of Opposed Compressors on an M-10 Base. Chemical and Petroleum Engineering, 12(3-4), March-April 1976, pp. 362-366.

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BEP.

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HATCH COVERS

H. A. Ivers

Paper No. 6. Session 1979-80

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HATCH COVERS

by H. A. Ivers

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Senior Ship Surveyor
LLOYD'S REGISTER OF SHIPPING

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NOTE: Metric units are used throughout this paper.

1. INTRODUCTION

Hatchways are the openings in decks which provide the vertical access to cargo spaces, or other spaces below these decks.

Hatch covers can be described as the means whereby a deck is rendered intact in way of these openings, and in the case of exposed weather decks serve to achieve the weathertight integrity of the decks. It is the intention of this paper to deal specifically with hatch covers closing the exposed and internal cargo hatchways of dry cargo ships and combination carriers. Also, as very few ships are now fitted with wooden covers, tarpaulins and battens, only contemporary mechanical covers will be considered.

A wide variety of hatch cover designs have been developed in recent decades to suit the changes in ship types and arrangements.

Therefore, it is the purpose of this paper to review the various aspects influenced by this development, and the changes in design standards that have evolved.

The paper can only treat certain of the items in a general manner, and it is hoped that the colleagues in Headquarters and outports will contribute to the paper to enlarge its scope.

2. HISTORY

The year 1980 records the sixtieth anniversary of the founding of the Lloyd's Register Technical Association and during this intervening time the only paper dealing with this subject was given by Mr J. G. Buchanan on 3 December 1936. (Ref. 1)

The paper gave a comprehensive history of the development of hatchways up to that time, and related to the standards for hatchways and covers given in the Load Line Rules 1932, as defined by the 1930 Load Line Convention.

The information contained in the paper makes interesting reading for deeply interested parties, but for the purpose of this paper I would like to quote only the following relevant paragraphs:—

> "It may appear strange, but it is nevertheless true, that until 1932 there were no statutory detailed regulations for the construction and closing of hatchways; classed vessels, of course, were obliged to conform to their own Society's requirements, but an owner of a vessel which was not classed with any of the registration societies could have his own ideas, within limits, of how best to close these deck openings, and if the Board of Trade did not consider the scantlings or arrangements quite satisfactory, they could not, with ease, compel the owner to conform to their way of thinking."

and

> "In 1933, Lloyd's Register amended its Rules, regarding hatchways, to agree with the statutory rules; very little alteration, however, was required as the Convention rules practically were what Lloyd's Register had been applying since 1915."

It can be seen from this that the Society had already developed and applied certain standards for hatchways long before they were defined by the Convention.

The statutory requirements were formulated for wooden covers in association with portable steel beams, and any proposals for substituting the wooden boards by metallic types, or fitting weathertight metal covers, would have been based on these requirements.

From our records, it would appear that the first weathertight steel hatch covers submitted to the Society for consideration was in 1928, and there was little progress in the development and usage of this type until after the Second World War.

When this type of cover eventually gained popularity, and was adopted by many owners, the Society formulated strength, stiffness and gasketing requirements based on the experience of the weathertight metal covers already in service.

In 1966, the International Conference on Load Lines was convened in London by the Inter-Governmental Maritime Consultative Organisation (IMCO) with the purpose of revising the Rules governing the assignment of freeboards on account of the developments in ship design and arrangements which had taken place since the 1930 Load Line Convention, and the experience gained since that time. The relative efficiency of hatchway closing appliances was discussed at this conference and standards of strength and stiffness were defined for weathertight metal covers.

Since 1966 the economics of the fast cargo turnaround, and the specialised ships developed to facilitate this, has accelerated the adoption and development of a multiplicity of weather deck and 'tween deck hatch cover types.

3. LOAD LINE ASPECTS

The regulations of the "International Convention on Load Lines, 1966" which apply specifically to the hatchways and hatch covers are summarised as follows:—

3.1 Position of Hatchways

For the purpose of the regulations, two positions of hatchways on weather decks are defined as follows:—

Position 1 — Upon exposed freeboard and raised quarter decks, upon exposed superstructure decks situated forward of a point located a quarter of the ship's length from the forward perpendicular.

Position 2 — Upon exposed superstructure decks situated abaft a quarter of the ship's length from the forward perpendicular.

The strength and stiffness criteria for hatch covers and height of hatchway coamings are defined, and are governed by their relative position on the ship.

3.2 Type of Hatchways

Where closed by portable covers and secured weathertight by tarpaulins and battening devices:—

— The requirements for hatch covers and portable beams are defined.

— The requirements for pontoon covers are defined.

Where closed by weathertight covers of steel or other equivalent material fitted with gaskets and clamping devices:—

— The requirements for weathertight covers are defined. The means for securing and maintaining weathertightness are to be to the satisfaction of the Administration and are to be such as to ensure that the tightness can be maintained in any sea conditions. For this purpose, tests for tightness are required at the initial survey, and may be required at periodical surveys, and at annual inspections or at more frequent intervals. See paras. 9.2 and 9.3 for the Society's requirements.

3.3 Basic Ship Types

For the purpose of freeboard computation, ships are divided into the following types:—

Type 'A' Ships — Ships designed to carry only liquid cargoes in bulk, and in which cargo tanks have only small access openings closed by watertight gasketed covers of steel or equivalent material.
Such ships have a high integrity of the exposed deck, and because of the degree of subdivision usually provided and low permeability of loaded cargo spaces, they have also a high degree of safety against flooding.

Type 'B' Ships — All ships other than Type 'A'.

Basic Type 'B' Ships are required to have steel pontoon hatch covers in association with tarpaulins, or weathertight steel hatch covers with gaskets and clamping devices.

In addition to the basic Type 'B' Ship, there are three sub-categories of this type as follows:—

B-100 Ships — Ships over 100 metres in length, so subdivided as to satisfy floatability requirements when loaded to the summer draught, if any two adjacent fore and aft compartments, neither of which is the machinery space, are flooded.

B-60 Ships — As for B-100 Ships, except that the floatability is assessed on the basis of the flooding of any single damaged compartment.

B+ Ships — Ships which in Position 1 have hatchways closed by portable wooden, or other material, covers supported by portable beams secured weathertight by tarpaulins and battening devices.

The type of hatch cover is governed by the selection of ship type, and ships in the first two sub-categories can have freeboards less than the basic Type 'B' ship, provided the covers in Positions 1 and 2 comply with the requirements for clamped gasketed covers and have adequate strength and stiffness. B+ ships are subject to an increased tabular freeboard.

3.4 Hatchway Coamings

The height of coamings above the upper surface of the deck, measured above sheathing if fitted, for hatchways closed by portable covers secured weathertight by tarpaulins and battening devices, is not to be less than: —

Position 1 — 600 mm

Position 2 — 450 mm

Where hatchway openings in these positions are closed by steel covers fitted with gaskets and clamping devices, these minimum heights also apply but may be reduced, or the coamings may be omitted entirely, if the safety of the ship is not thereby impaired in any sea conditions. In such cases, special attention is given to the strength and stiffness of the covers, to their gasketing and securing arrangements and to the drainage of recesses in the deck. Also, the agreement of the National Authority concerned is required.

For type 'B-100' or Type 'B-60' ships, the height of coamings may require to be increased, where this is shown to be necessary by the floatability calculations required by the Convention.

3.5 General

The Load Line Regulations concerning protection of openings are incorporated in the Society's Rules, and certain of the requirements will be considered in more detail when dealing with particular items.

However, additional statutory requirements may be requested by the National Authority of the country in which a ship is to be registered, but these are not considered in this paper.

4. SELECTION AND STOWAGE CRITERIA

4.1 Weather Deck Covers

The type of hatch covers on the weather decks of the basic ship types defined in para 3.3 are specified below and may be used in the types of ships as indicated in Table 1.

Definitions of cover types:

(a) Steel plated cargo hatch covers stiffened by webs or stiffeners and secured by clamping devices. Weathertightness to be achieved by means of gaskets. Hatch covers used for holds containing liquid cargoes are included in this category.

(b) Steel plated cargo hatch pontoon covers having interior webs and stiffeners extending for the full width of the hatchway. Weathertightness to be obtained by tarpaulins.

(c) Hatch covers of wood or steel used in conjunction with portable beams. Weathertightness to be obtained by tarpaulins.

(d) Access hatch covers for cargo oil tanks and adjacent spaces. The hatch covers are to be of steel and gasketed.

(e) Access hatch covers other than (d). For Type 'A', Type 'B-100' and Type 'B-60' ships, the covers are to be of steel, and weathertightness is to be achieved by means of gaskets.

Table 1

Covers associated with ship types.

	Type of Ship				
Type of cover	'A'	'B-100'	'B-60'	'B'	'B+'
(a)	—	X	X	X	X
(b)	—	—	—	X	X
(c)	—	—	—	—	X
(d)	X	X	X	Not Applicable	
(e)	X	X	X	X	X

It is considered that covers types (b), (c), (d) and (e) are adequately covered in the Society's "Rules and Regulations for the Classification of Ships" and, therefore, as mentioned in the Introduction, only covers type (a) are being dealt with in this paper.

4.2 'Tween Deck Covers

'Tween deck hatch covers may be any of the types defined in Table 1, but they need not be gasketed unless fitted to deep tanks, or water ballast holds or compartments, in which case the covers are to be of type (a) and oiltight or watertight as appropriate.

4.3 Operational Aspects

On account of the variety of methods of opening, closing and stowing hatch covers, the selection and stowage criteria are considered by the Society to be operational aspects and not classification items.

For this reason, the designer and manufacturer retain a free hand to develop new designs to accommodate the advancement in cargo stowage and handling techniques.

In other words, provided the hatchways comply with the Rules for height, scantlings, and stiffening of coamings, strength and stiffness of covers, gasketing and cleating arrangements, weathertightness, and the covers open and close satisfactorily, then this would be sufficient for classification purposes. The hydraulic systems—unless used for the operation of hydraulic cleats—, chains, wires and other operational machinery are not considered classification items. However, the Society would show interest in any item considered to be a potential hazard, or had a bearing on weathertightness capability.

4.4 Operational Philosophy

The commercial design and construction of hatch covers, and their accessories, are normally covered by the manufacturers patents, and it is not practical to give detailed descriptions and specifications of all the various covers currently available. For full information, reference should be made to the technical brochures issued by the manufacturers, and to the publication "Cargo access equipment for merchant ships" (Ref. 3), which gives ample coverage of this subject, along with the history of their development.

Table 2

Description of Cover	Operational Method	Locational Suitability
(a) Single pull	Rolling and tipping by electric power, hydraulic power, or the ship's cargo gear	Weather deck
(b) End or side rolling	Rolling by electric or hydraulic power	Weather deck
(c) Single piece	Lifted off by the ship's cargo gear or shore crane	Weather and 'tween decks
(d) Piggy-back (lift and roll)	Lift and roll by electric or hydraulic power	Weather deck
(e) End or side folding	Folding by hydraulic power or the ship's cargo gear	Weather and 'tween decks
(f) Roll stowing	Roll stowing by electrical power or hydraulic power	Weather deck
(g) Sliding and nesting	Sliding, nesting and tipping by electrical power	'Tween decks
(h) Direct pull	Rolling and tipping by ship's cargo gear, crane, electric power or hydraulic power	Weather deck

The basic stowage operational methods of these covers are, in general, summarised in Table 2, and shown in Fig. 1.

The single pull multi-panel hatch cover is the most commonly adopted of all the various types now in service. Fig. 1a and Plate 1 show the stowage operation. Fig. 2 shows a typical single pull cover and indicates the terms used in hatch cover technology.

To open a single pull cover the securing cleats are released and each panel is raised by portable jacks while the eccentric rolling wheel is rotated into its rolling position. Alternatively, the wheel is housed in a recess in the coaming rest bar and is lifted into the rolling position by a hydraulic pot lift, see Plate 2, or by a hinged plate.

The cover panels are now free to move in the fore and aft direction within the guides on the coaming rest bar. It is set in motion by means of a pulling wire from the winch attached to the centre of the furthest edge of the 'pusher' panel. See Fig. 2.

As the wire is tightened the panels are each pushed beyond the end coaming. On reaching the end of the hatchway the weight of each panel is transferred from its wheels to the balancing rollers, situated near its mid-length, which engage with the rising track extension. See Fig. 2. As the centre of gravity of each panel is situated slightly towards the stowage end of the panel it tips into the vertical position and is pushed towards the end of the stowage space by the next panel to arrive. When the opening operation is completed the panels are secured in place by retaining hooks or chains.

For the closing operation the backhaul wire is rigged, see Fig. 2, and the 'pusher' panel is pulled back over the hatchway. As the first panel leaves its stowage position it tips about its rollers to land horizontally with its wheels resting on the coaming. It is pulled further along the hatchway and by means of the link chains pulls the next panel until it tips into the horizontal position.

This operation is repeated automatically until all panels are in the closed position. During the tipping process, the leading edge of the tipping panel engages in the trailing edge of the preceding panel, to mate and form the cross-joint seal.

This type of hatch cover is still the most popular, and later models have adopted connecting rods in lieu of chains, a motorised 'pusher' panel, and other variations.

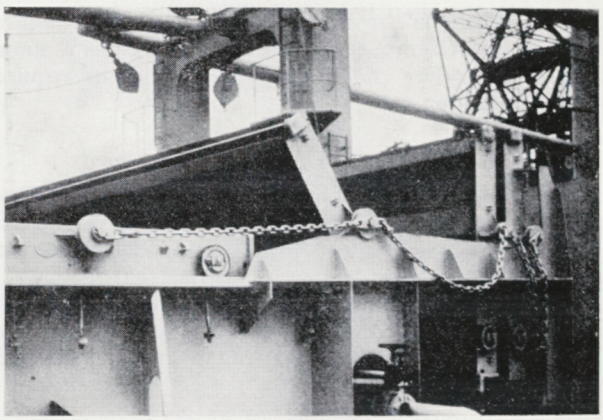


PLATE NO. 1

Stowage operation of single pull cover.

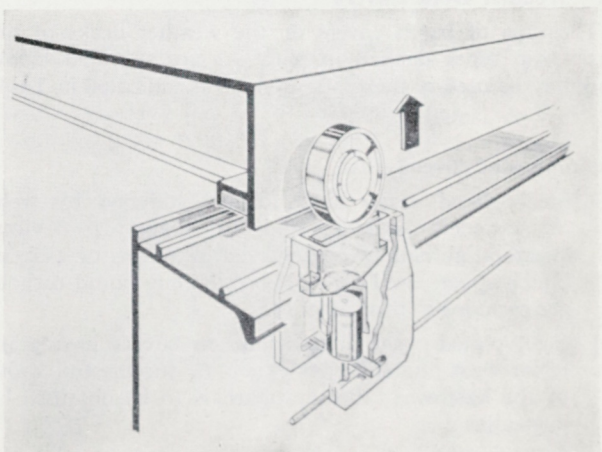
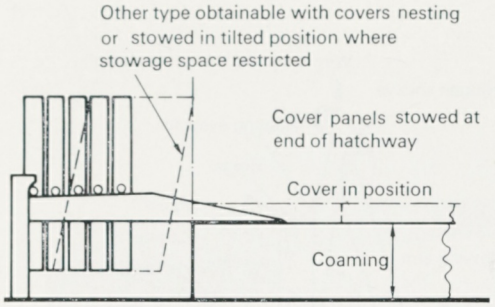
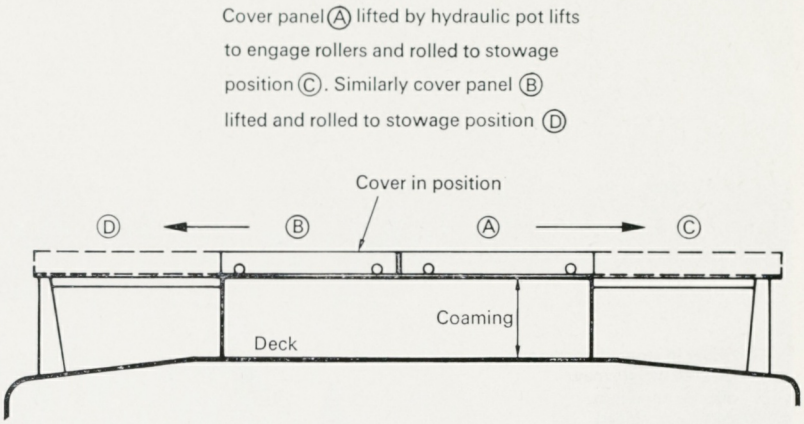


PLATE NO. 2

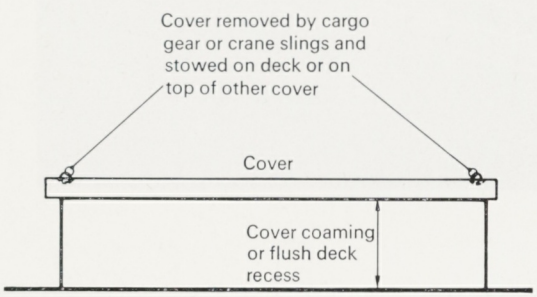
Hydraulic pot lift for rolling wheel.



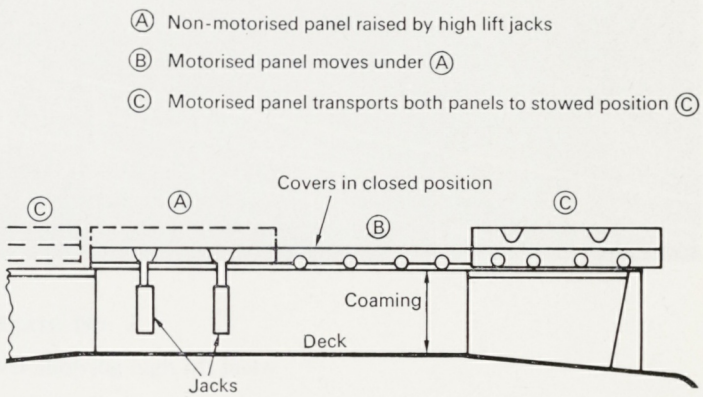
1(a) Single pull cover



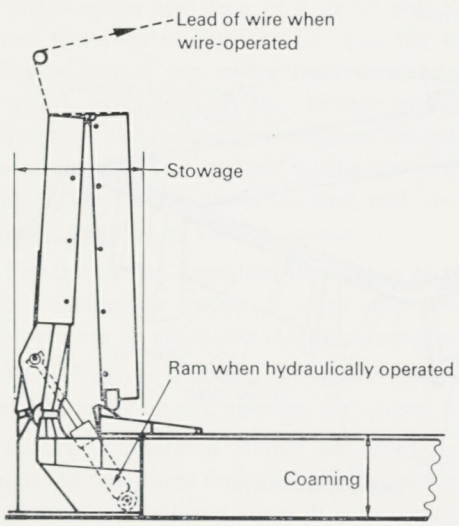
1(b) Side or end rolling cover



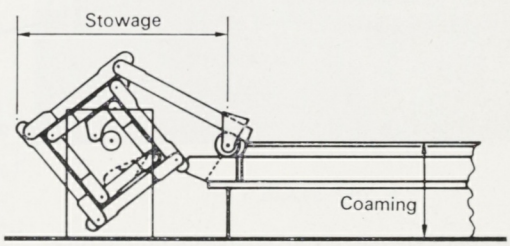
1(c) Single piece cover



1(d) Piggy-back (lift and roll) cover

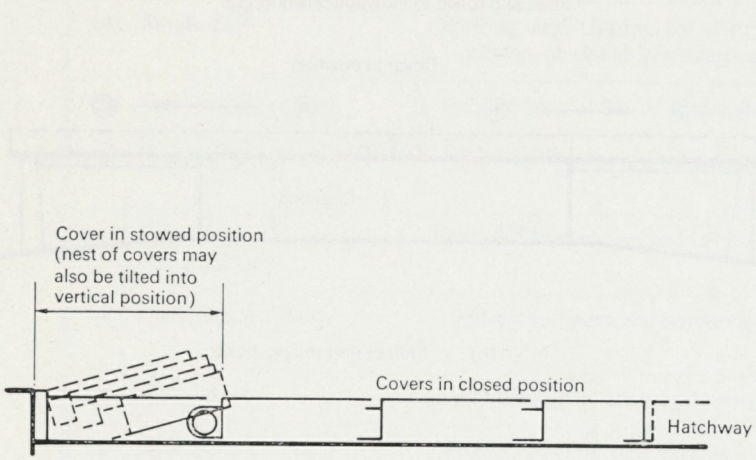


1(e) End or side folding cover

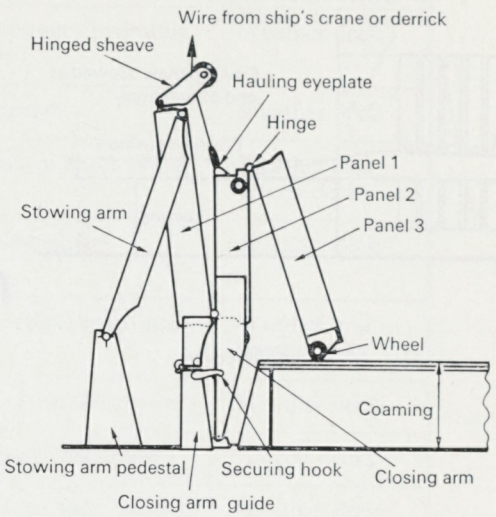


1(f) Roll stowing cover

FIG. 1
Basic stowage methods for covers.



1(g) Sliding and nesting cover



1(h) Direct pull cover

FIG. 1 (Contd.)

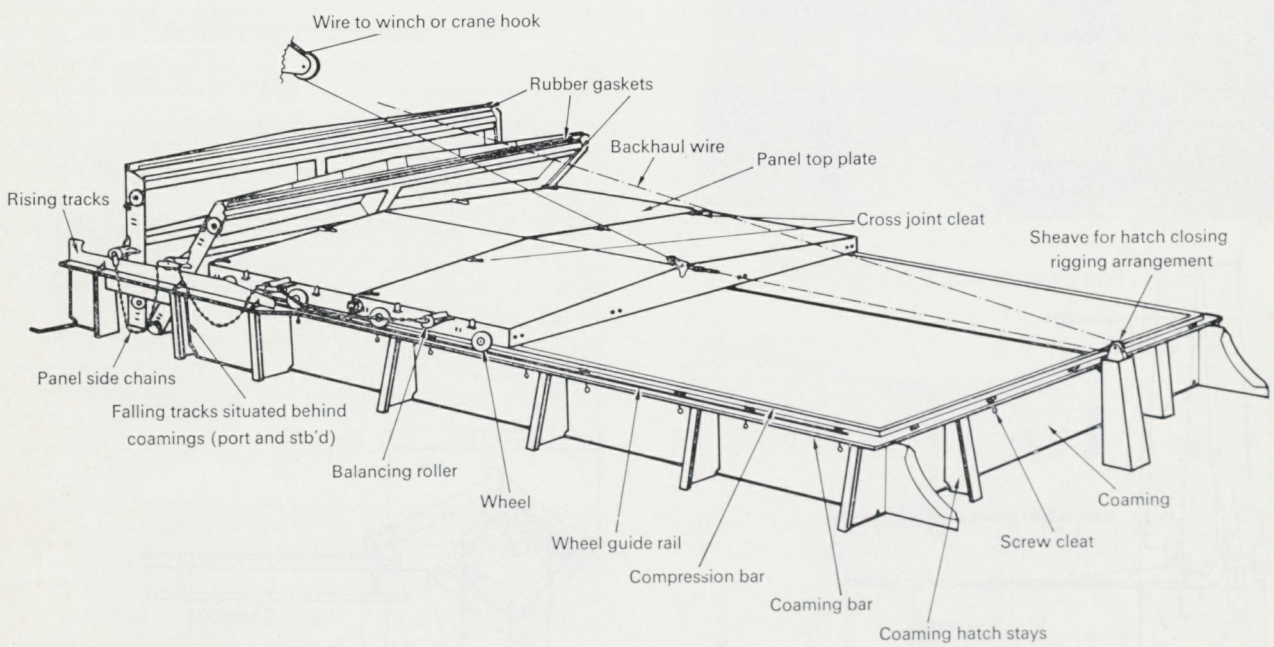


FIG. 2
Typical exposed multi-panel cover (single pull).

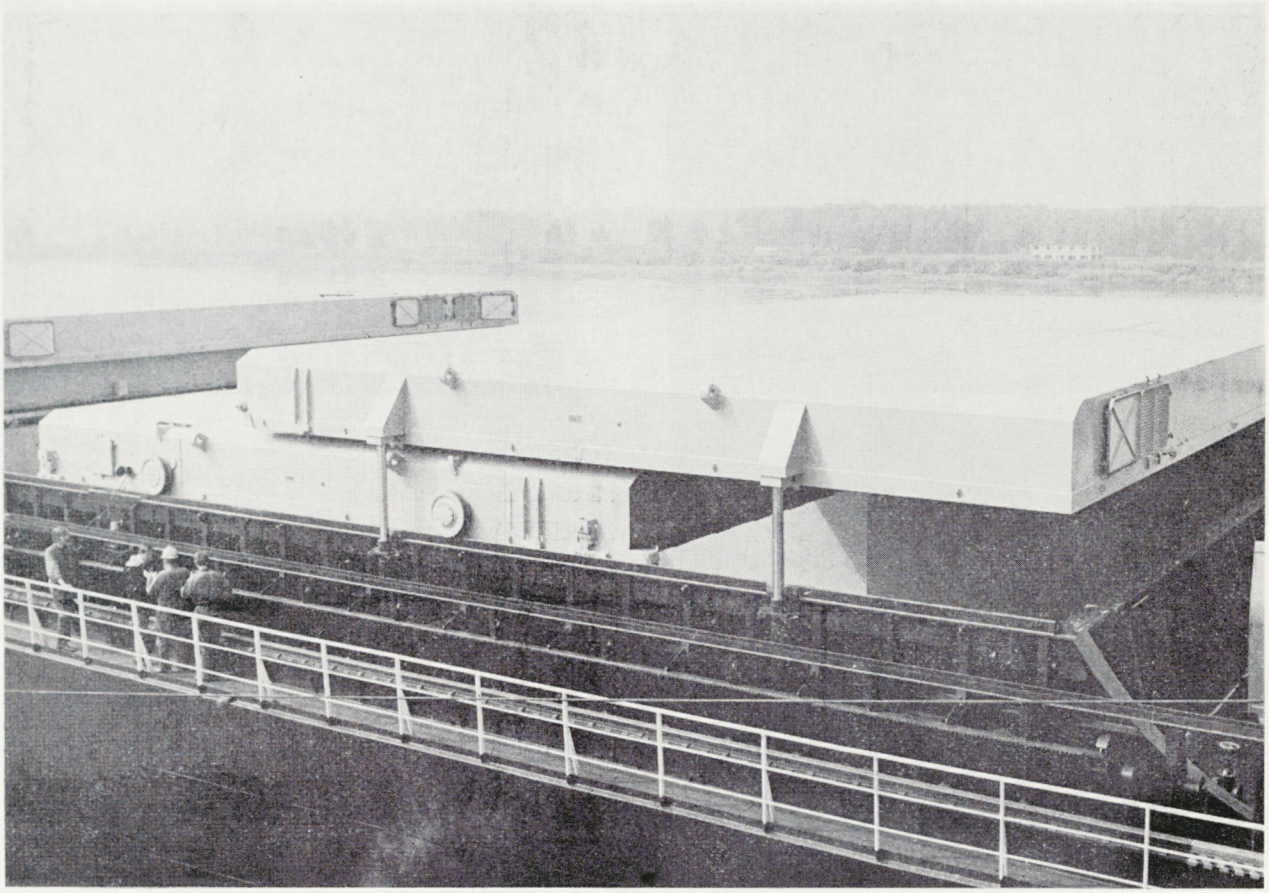


PLATE NO. 3

Piggy back cover showing high lift jacks.

The closing and opening operations of a piggy-back (lift and roll) hatch cover are shown in Fig. 1d. Plate 3 shows a typical cover with the high lift jacks in operation.

The stowage operation of a direct pull automatic hatch cover is shown in Fig. 1h. To open the hatch cover the crane or derrick wire raises the sheave and panel 1. Panels 2 and 3 move towards the stowage position but remain horizontal. The closing arm contacts the guide, see Plate 4, and is deflected downwards raising the hinges of panels 2 and 3. The panels move together and are locked in the stowage position by securing hooks.

For the closing operation the wire is re-attached to take the strain and the cover is lowered under gravity. This type of cover has an automatic cleating arrangement.

Plate 5 shows a rolling wheel for the direct pull cover with the cover in the opening and closed positions.

Particular attention should be given to arrangements similar to this where the wheels are housed in recesses when the covers are battened down. It is to be ensured that there is sufficient clearance in the recess to accommodate any hatchway deformations or cover movements. It is also important that the wheels are properly housed in the recesses during the battening down of the hatches. This would also apply to the pot lift shown in Plate 2.

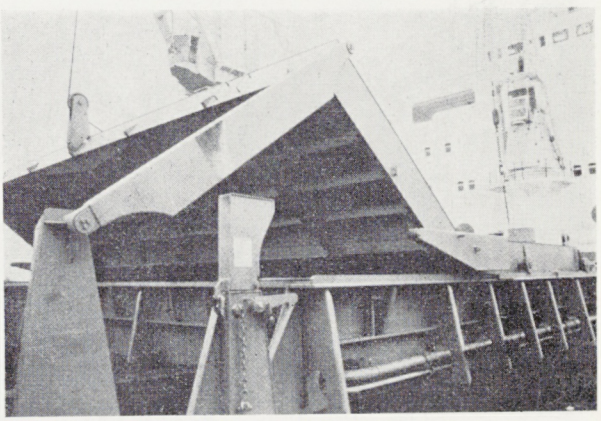


PLATE NO. 4

Direct pull automatic cover showing the closing arm approaching the closing arm guide.

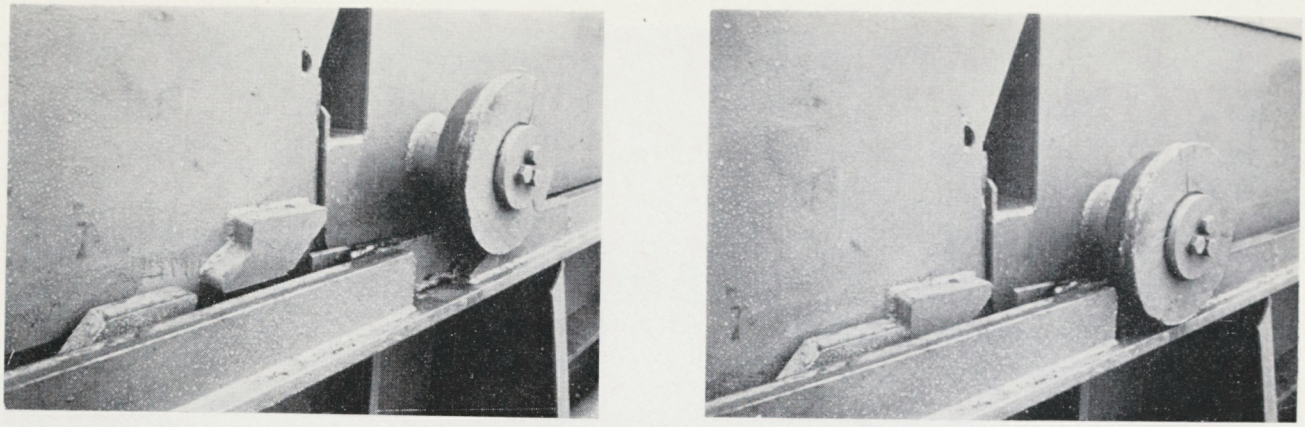


PLATE No. 5

Rolling wheel of a direct pull cover showing cover in opening position and in closed position.

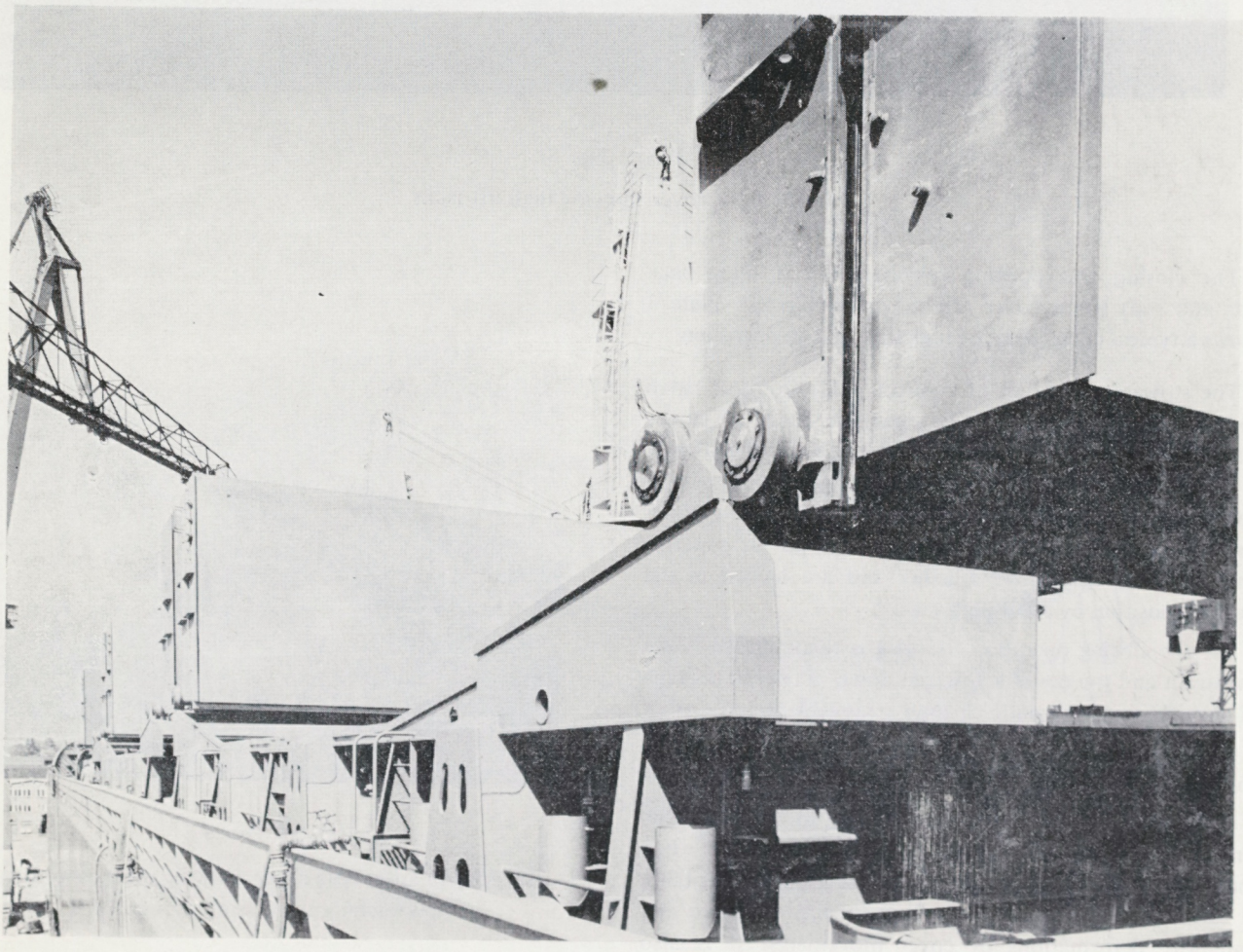


PLATE No. 6

Multi-panel, external ram, hydraulic folding covers, showing covers in stowed position.

A multi-panel, external ram, hydraulic folding hatch cover, showing the covers in stowed position, is shown in Plate 6. These covers are installed on a 50,000 tdw bulk carrier classed with the Society, and the steel weight per hatch is approx. 200 tons.

The external rams for the hatch cover in Plate 6, are shown in Plate 7.

Plate 8 shows the opening operation at a folding hatch cover for a smaller ship.

Roll stowing exposed hatch covers have been introduced to reduce the deck space required for stowage. Plate 9 shows a roll stowing cover in the stowed position.

Plate 10 shows the closing operation for a roll stowing cover. This type of cover also has an automatic cleating arrangement.

Side rolling covers were developed for bulk, and combination carriers. Plate 11 shows single piece side rolling covers.

Single piece lift on/lift off hatch covers were developed for container ships. Plate 12 shows a containership with a typical arrangement of these hatch covers.

PLATE No. 7
The arrangement of external rams for the covers shown in Plate 6.

4.5 Selection of Covers

From the shipowner's point of view, the selection of the particular make of cover will be influenced by the following considerations in conjunction with the initial cost:

(1) Simple and speedy operation to obtain quick cargo turn around with a minimum number of crew.

(2) Safety, reliability and economy from the maintenance aspect.

(3) Type of deck cargoes envisaged and deck space available for stowage, e.g. timber, containers.

(4) Clear height for stowage in relation to height of coamings.

(5) Loading on covers, minimum statutory and Rule or increased to suit operational requirements.

(6) Available shipboard operating machinery or source of power.

(7) Means of achieving weathertightness related to the cargoes envisaged, and whether manual or automatic cleating.

(8) Weight of covers and accessories. The weight of single piece covers is especially important being restricted by the capacity of the available cranes.

(9) Service experience of similar covers on other ships.

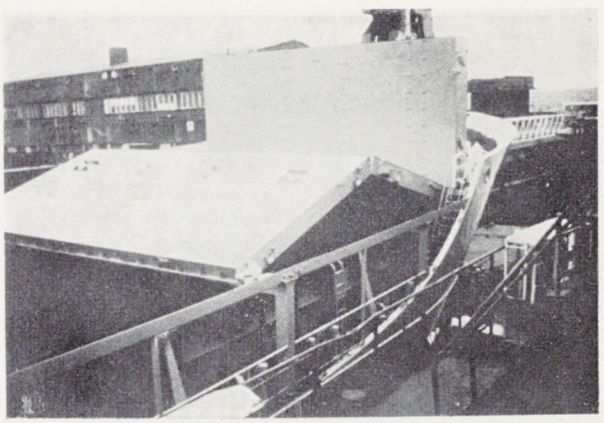


PLATE No. 8
Folding covers showing opening operation.

4.6 General

Some of the above aspects involve the Classification Societies and must satisfy their requirements, and these will now be dealt with in greater detail.

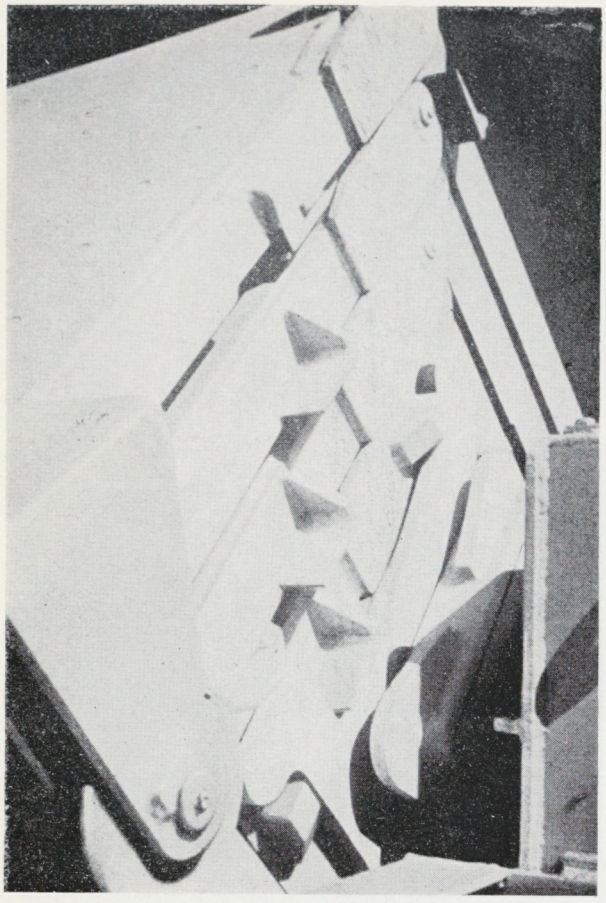


PLATE No. 9
Roll stowing cover in stowed position.

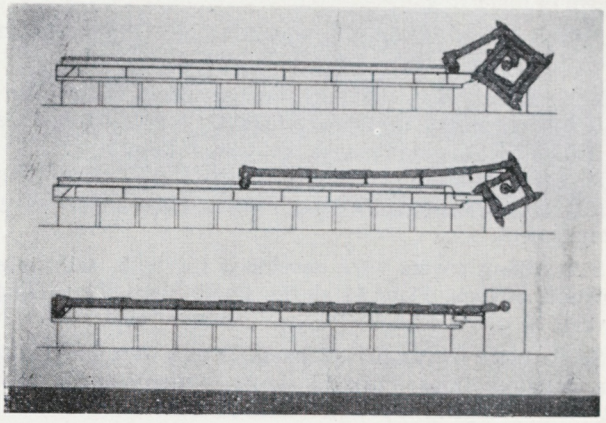


PLATE No. 10
Roll stowing cover showing closing operation.

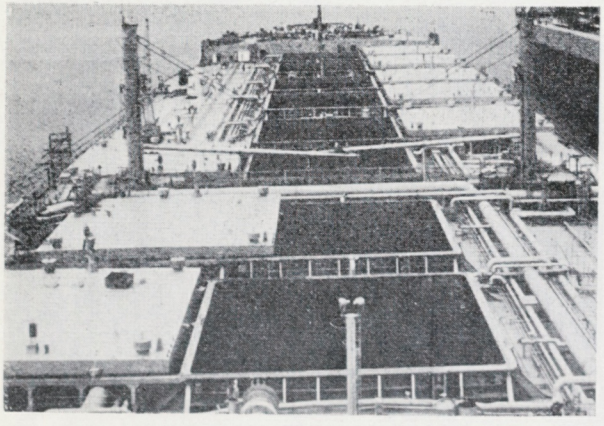


PLATE No. 11
Single piece side rolling covers.

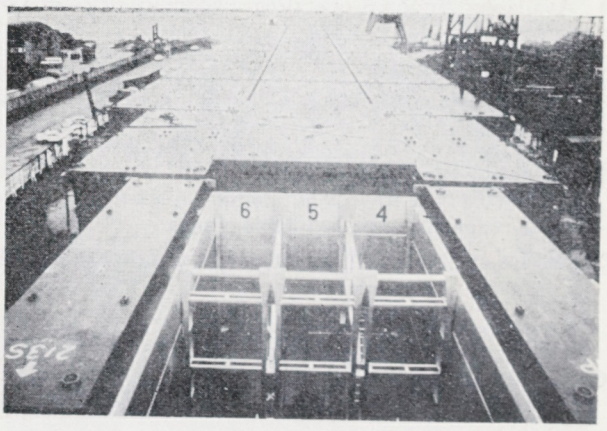


PLATE No. 12
Container ship single piece lift on/lift off hatch covers.

5. EFFECT OF HULL STRUCTURAL DEFORMATIONS

5.1 General

The installation and testing of hatch covers are carried out when the ship is in the lightship condition in the shipyard. The hull structural deformations change when the ship is loaded or ballasted in port, or when she goes to sea in either of these conditions. The principal components are attributable to the vertical and transverse bending, and torsional displacement of the main hull girder.

The examination of their influence on the structure is important, but for the purpose of this paper the comments relating to the principal components will be confined to their effect on hatchway deformation.

In general, the traditional ship had small cargo hatchways in association with a large area of deck which minimized the deformation. In recent years, however, with ships becoming larger, and hatchways forming the greater percentage of the deck area, this could be of sufficient magnitude to warrant consideration at the early design stage of the hatch covers. Ships with this hatchway configuration are generally referred to as "open-type" ships.

The relative hatchway distortion is of prime importance, and allowance must be made for this when designing the hatch cover installation, in order to achieve compatibility with the ship's structure. Also, it is apparent that unless the shipbuilders and hatch cover manufacturers take account of this, then the hatch covers may be unsatisfactory in service.

5.2 Vertical Bending of Hull Girder

The effect of a hogging bending moment on a number of ships varying from 112 metres in length to 273 metres in length is shown in Table 3, and the resulting deflections and elongations could be considered as the maximum calculated over 20 years of ship life. See also Fig. 3.

It will be noted from Table 3 that, while the radius of curvature of the ship's bending axis increases with ship length, the vertical deflection of the upper deck over one hatch length decreases. The elongation per unit length does not vary as the design stress is constant over the range of ship lengths.

The deformations of hatchways due to the bending of the hull girder and local loading can also be illustrated by the results for a detailed analysis of the structure of a 120 000 ton deadweight bulk carrier carried out by the Society.

Figures 4 and 5 show the extent of deformation resulting from homogeneous and alternately loaded hold conditions in still water.

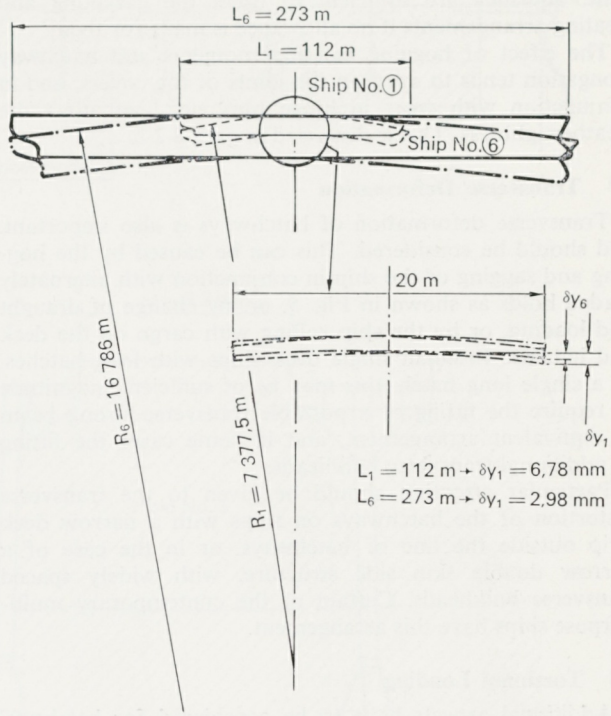


FIG. 3

Comparison of calculated hull girder deflections for various lengths.

Figure 4 shows the deformations corresponding to a sagging still water bending moment 37 per cent of the maximum permissible value.

Figure 5 shows the deformation corresponding to a hogging still water bending moment 55 per cent of the maximum permissible value. In this case the ship is loaded in alternate holds, and it should be noted that the rotation of the transverse bulkheads has had a direct influence on the deformation of the hatch openings.

Table 3

Ship	Length m	Deadweight tonnes	Radius of curvature R	Estimated deflection due to SWBM+VWBM mm	Deflection over 20M mm	Elongation over 20M mm
1	112	8000	7377,5	212	6,78	16,42
2	140	15 115	8765	279	5,7	16,42
3	164	24 500	10 048	335	4,98	16,42
4	192	43 200	12 189	378	4,10	16,42
5	243	69 000	14 087	524	3,54	16,42
6	273	145 000	16 786	555	2,98	16,42

The deformations shown in Figs. 4 and 5 would be augmented by any increase in still water bending moments, and also by the addition of the wave bending moments. The deformations are not exceptionally large, nor permanent, but they are sufficient to upset the gasketing and cleating arrangements if no allowance is made for them.

The effect of hogging bending moments and hatchway elongation tends to open up the joints of the covers, and in conjunction with wear in hinge pins etc., can affect the weathertightness. This is discussed in para 8.2.2.

5.3 **Transverse Deformation**

Transverse deformation of hatchways is also important, and should be considered. This can be caused by the hogging and sagging of the ship in conjunction with alternately loaded holds as shown in Fig. 5, or, by change of draught and loading, or by the ship rolling with cargo on the deck and hatches. In small single deck ships with long hatches, or a single long hatch, this may be of sufficient magnitude to require the fitting of a portable transverse strong beam or equivalent arrangement, and in some cases the fitting of additional transverse bulkheads.

Particular attention should be given to the transverse distortion of the hatchways on ships with a narrow deck strip outside the line of hatchways, or in the case of a narrow double skin side structure, with widely spaced transverse bulkheads. Certain of the contemporary multi-purpose ships have this arrangement.

5.4 **Torsional Loading**

Additional aspects have to be considered for hatchway deformation of "open-type" ships.

Firstly, the width and in-plane rigidity of the cross-deck structure between hatchways have an important influence on the magnitude of hatchway opening deformation. In the case of container ships and other "open-type" ships, this cross-deck structure has been substantially reduced in width with corresponding reduction in the in-plane rigidity. Also, to accommodate wide hatchways, the outboard deck structure consists of a narrow deck strip, which in most cases comprises part of a topside box structure or double skin structure.

Secondly, in the case of "open-type" ships, torsional aspects become of major importance, and the nature of a ship's response to torsional loading is dependent on the length of the open section, the degrees of fixity at the ends of the open section, and the bending and torsional rigidity of the cross-deck strips between hatchways. Fig. 6 shows the outline idealized transverse section of an "open-type" ship in way of bulkhead and the deformation induced by the torque loading.

The Society uses main frame, or desk top computer programs to determine the magnitudes of the torsional stresses and deformations. Table 4 shows part of the output from the Society's computer program and from this information the amount of the hatchway opening deformation shown in Fig. 7 is calculated, using the expression:—

$$\Delta d = \sqrt{(l+u_2) + (b+\Delta v)^2} - \sqrt{l^2+b^2}$$

where u_2 = relative warping displacement of node 2 in respect to node 3.

Δv = relative transverse movement of node 2 in respect to 1, which is given by

$$\Delta v = -(D+\epsilon)\ (\theta_2-\theta_1)$$

and

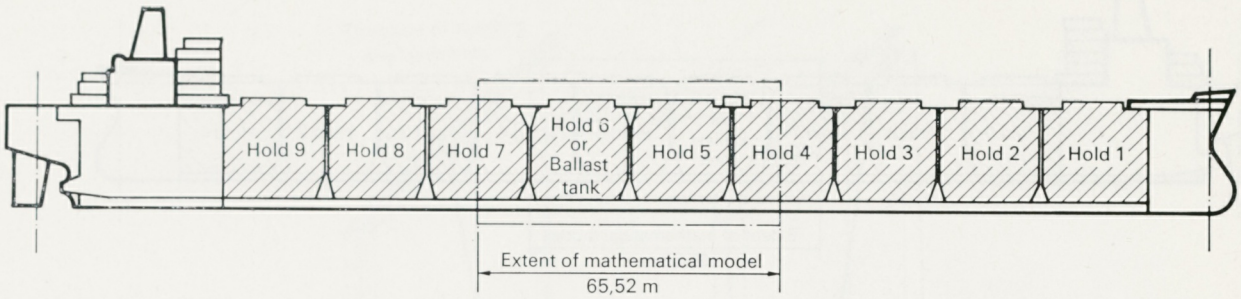
D = depth mld. + height to top of coaming from deck

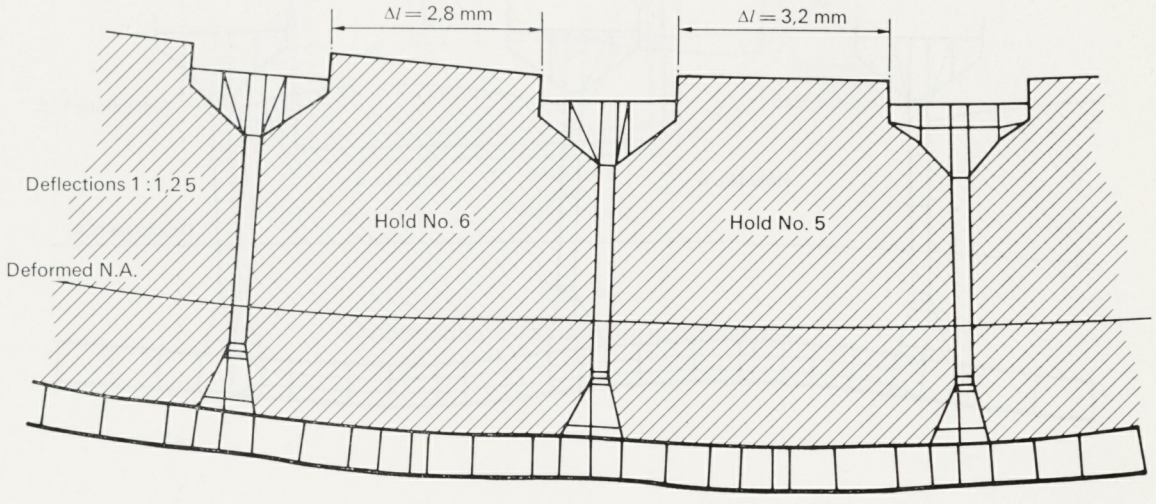
ϵ = distance from shear centre to base line.

Table 5 shows the calculated values in change of shape of the hatch opening and diagonals for a container ship.

This calculation has indicated the warping displacements due to the torsional loading. In addition to these, longitudinal strains due to a combination of still-water and wave bending moments could result in greater combined fore and aft displacements of the hatchway opening.

The distortion of hatch openings in these "open-type" ships can effect the covers in relation to weathertightness, where this is required, transverse and fore and aft sliding movement, and wear of contact surfaces between hatch cover skirt and coaming. These items are dealt with in detail in para 8.2.1.





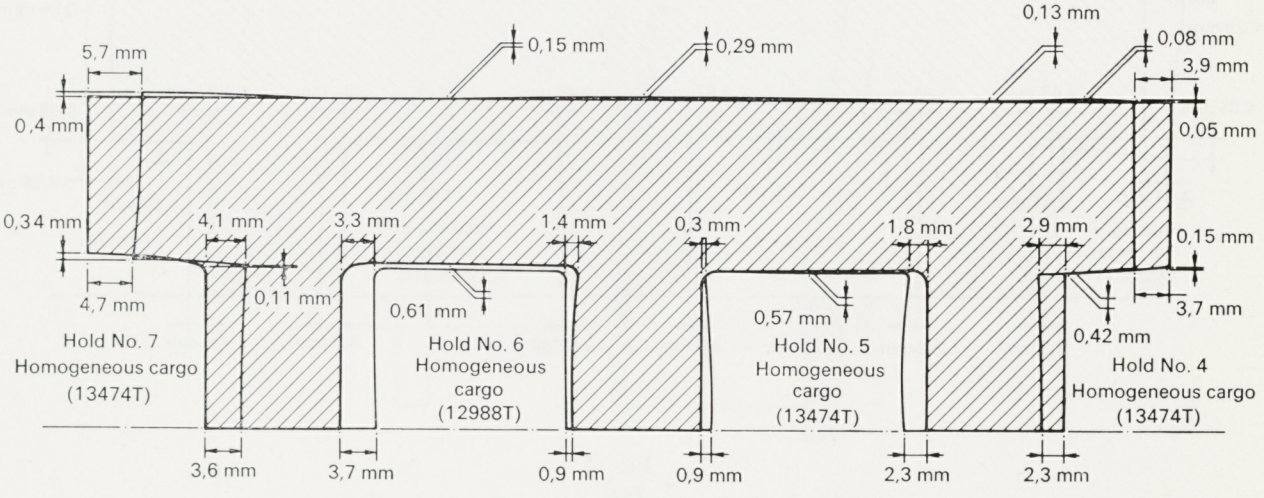


FIG. 4

120,000 tdw. Bulk carrier, sagging still water bending moment.

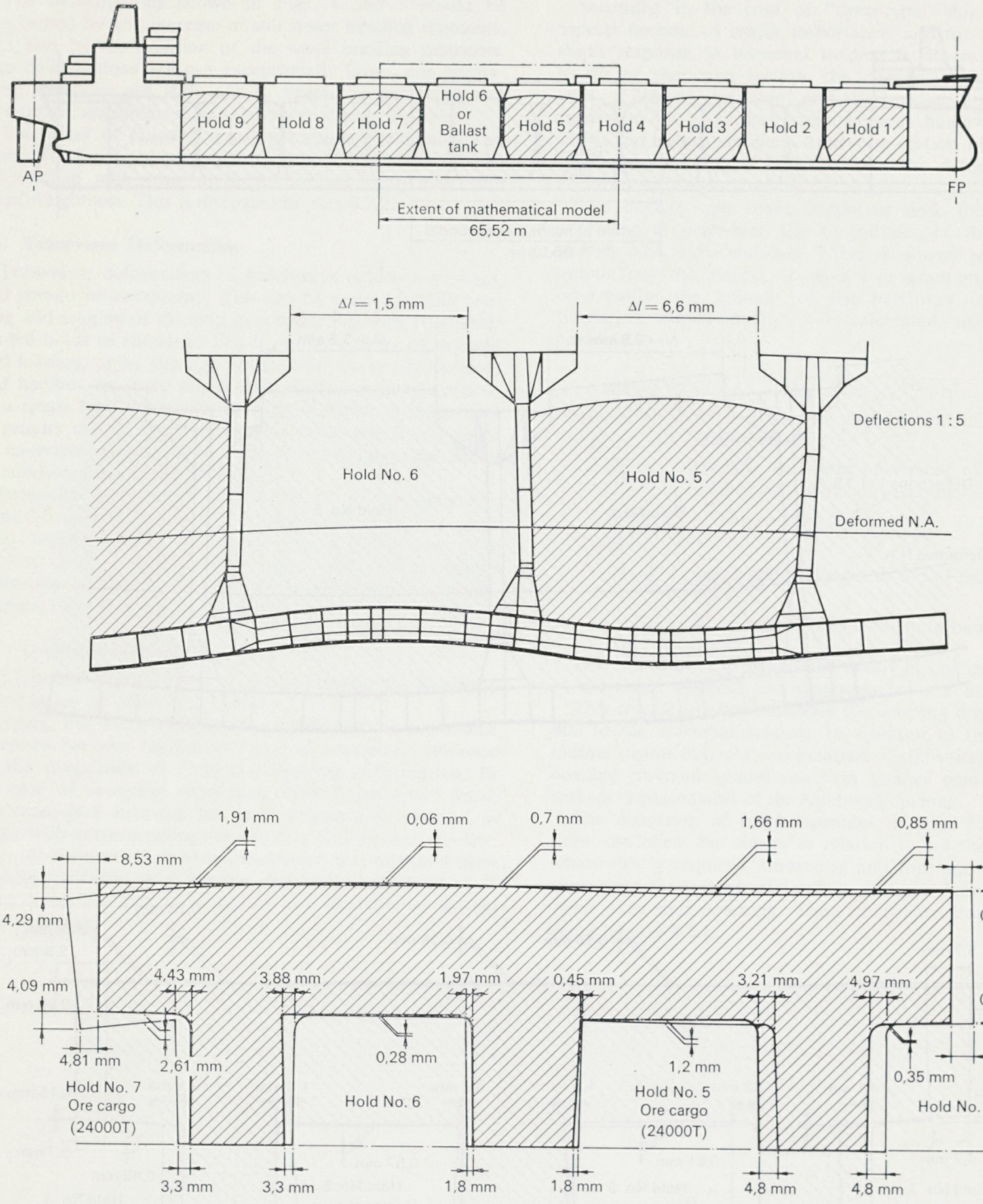


FIG. 5

120,000 tdw. Bulk carrier, hogging still water bending moment.

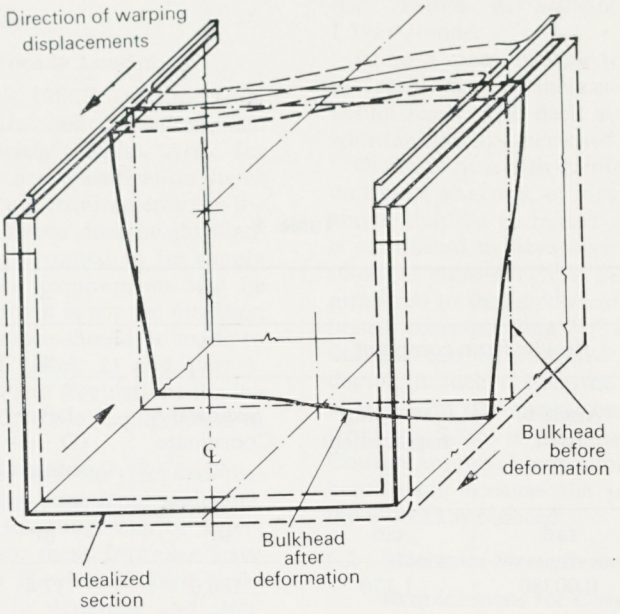


FIG. 6

Deformation induced by torsional loading.

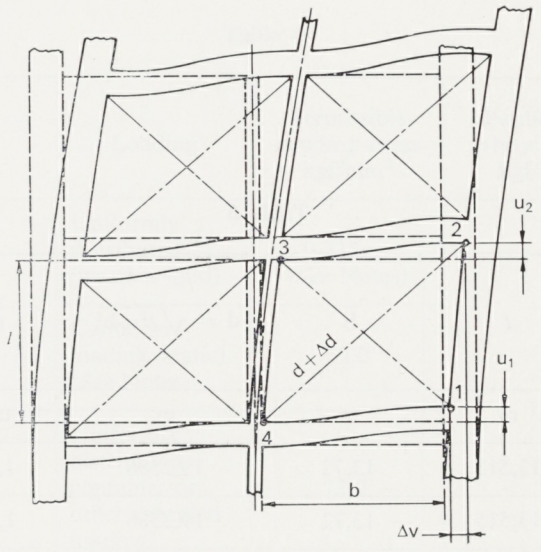


FIG. 7

Hatchway opening deformation for a containership.

Table 4

	1	2	3	4	5
	Results from computer				
Position	Angle of twist θ	Warping displacement U	Sectorial Coordinate w	Lever (D+ε+ coaming)	$\Delta\theta$
	rad	cm	m^2	m	rad
Hatch No. 7 (fore end)	0,00380	1,170	184,0	37,4	0,000924
Hatch No. 6 (aft end)	0,00383	1,170	184,0	37,4	0,000871
Hatch No. 6 (fore end)	0,00470	1,150	184,0	37,4	0,000871
Hatch No. 5 (aft end)	0,00479	1,07	184,0	37,4	0,000801

Table 5

$\Delta v=(4)\times(5)$ (*See* Table 4)	l	b	$d=\sqrt{l^2+b^2}$	u_2	Elongation increment of hatch diagonal Δd
cm	m	m	m	cm	cm
3,43	13,515	13,72	19,2586	1,17	3,265
3,25	13,515	13,72	19,2586	1,15	3,123
3,25	13,515	13,72	19,2586	1,15	3,123
3,0	12,88	13,72	18,8	1,07	2,92

6. DESIGN REQUIREMENTS AND APPRAISAL

6.1 Minimum Strength and Stiffness

Requirements for Covers Uniformly Loaded

For steel weathertight covers, the 1966 Load Line Convention defined the loadings, stresses and deflections, and these are incorporated in the Society's Rules. Also, for cargo 'tween deck covers, which are classification items only, the Society has formulated Rule requirements for the strength and stiffness related to a 'tween deck height loading. In both cases, the covers are assumed to be simply supported. Although certain of the requirements will be considered in more detail, at this time it is not the intention to deal with all of them; and reference should be made to "the 1966 Load Line Convention" (Ref. 2) and Part 3, Chapter 11, Section 2 of the "Rules and Regulations for the Classification of Ships" (Ref. 4) for these requirements in full.

The Rules, in general, apply to uniformly loaded rectangular multi-panel covers with uni-directional stiffening, and in the majority of cases the scantlings can be determined by the Rule formulae. Also, these formulae have been programmed for use on the Hewlett-Packard desktop computer, and are available to designers and shipbuilders (Ref. 5).

The scantlings derived from the formulae for the weather deck covers are based on design loads in terms of tonnes/m^2 which are related to the Position 1 and Position 2 referred to previously under Load Line Aspects. The higher inertial forces experienced at the forward end of a ship, and the greater possibility of shipping sea water account for the greater design load for Position 1.

Similarly for 'tween deck covers, the design load is based on the 'tween deck height at centreline from the 'tween deck to the underside of the hatch cover stiffeners on the deck above, in association with a stowage rate of 1.39m^3/tonne.

In both cases, heavier loading may be permitted only if the scantlings are increased in direct proportion to these design loads. The deck structure is also to be capable of withstanding this increased loading.

On ships of length greater than 125m, hatch covers fitted on top of a second, or virtual second, tier superstructure or above, may be permitted a reduction in scantlings. A ship is considered to have a virtual moulded depth at least one standard superstructure height less than the actual depth measured to the uppermost continuous deck when the freeboard corresponding to the required summer moulded draught can be obtained on the basis of the corrected depth. In such a case the first tier erection is considered as a second tier and so on. The standard height of superstructure, 2.3m, is the height defined in the "International Convention on Load Lines, 1966". This relaxation has been made because the probability of deck wetness on these decks is reduced.

6.2 Minimum Strength and Stiffness

Requirements for Covers with Point Loads

Where point loads are applied to rectangular multi-panel covers with uni-directional stiffening, the scantlings are to be determined by direct calculations, which in the majority of cases would involve the application of the simple beam theory with the panel considered as simply supported at two edges. The end panels could be considered as being supported on three edges.

Parameters of strength and deflection for direct calculations are given in the Rules, and these are shown in Table 6.

Table 6

Location	Item	Loading	Permissible bending stress kgf/mm^2	Permissible shear stress kgf/mm^2	Permissible deflection, metres
Weather deck, Position 1 and 2	Steel weathertight covers	Uniformly distributed (weather load)	$0{,}235\sigma_u$ (*See* Notes)	7,0	$0{,}0028l_o$ (*See* Notes)
		Container loading (static) (*See* Notes)	12,0		
Cargo 'tween deck	Steel covers	Uniformly distributed container or other specified loading	12,0		$0{,}0035l_o$

NOTES

1. Where weather deck hatch covers carry containers, the requirements for uniformly distributed weather loading are also to be satisfied.

2. The requirements for container loading on weather deck hatch covers may be applied to other specified loadings where it can be shown that there is equivalent protection from weather loads.

where l_o = unsupported span, in metres, and
σ_u = minimum ultimate tensile strength, in kgf/mm^2.

The covers in each case must also satisfy the Rule scantling requirements for uniform loading as previously explained in para. 6.1.

6.3 Grillage Formation

Where the covers are formed from orthogonally stiffened plate fields, a grillage type analysis is normally carried out to determine the distribution of bending moment and shear force between the components to obtain an optimisation of the scantlings.

This would also apply to covers where the panels are linked by hinges at the cross-joints which act as supports in the vertical direction. This is illustrated by Fig. 8, which shows a panel loaded by point loads near to the linkage with an adjacent unloaded panel and the percentage distribution of loading along each panel. This type of investigation is facilitated by a grillage type analysis, and the desired optimisation would be achieved by reducing the scantlings of the transverse stiffening member in proportion to its actual share of loading.

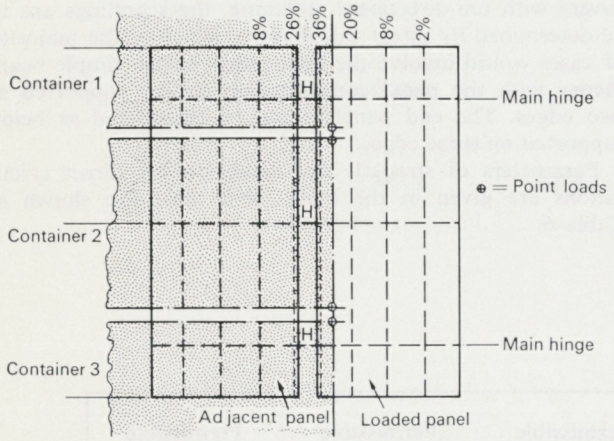


FIG. 8

Loading distribution for cover panels linked by hinges.

Alternatively, finite element techniques can be adopted where a minimum weight optimisation is desired and the buckling stability of the cover plating and stiffening elements has to be investigated.

The strength and stiffness parameters for grillage analysis are as shown in Table 6. However, the covers in each case must also satisfy the strength and deflection requirements for the Rule uniform loading, as previously explained.

Figure 9 shows a typical hatch cover for a containership. The hatch covers may be 2 or 3 abreast and the length is usually suitable for one 40ft or two 20ft containers. The earlier covers were suitable for two tiers of containers but the current designs now carry three tiers to suit operational requirements. See also para 6.4.3.

The weight is restricted by the lifting capacity of the container cranes and therefore minimum steel requirement is of prime importance.

This is another example of where the application of grillage and computer calculation methods can achieve an optimisation of the scantlings to obtain the minimum steel weight for a given loading.

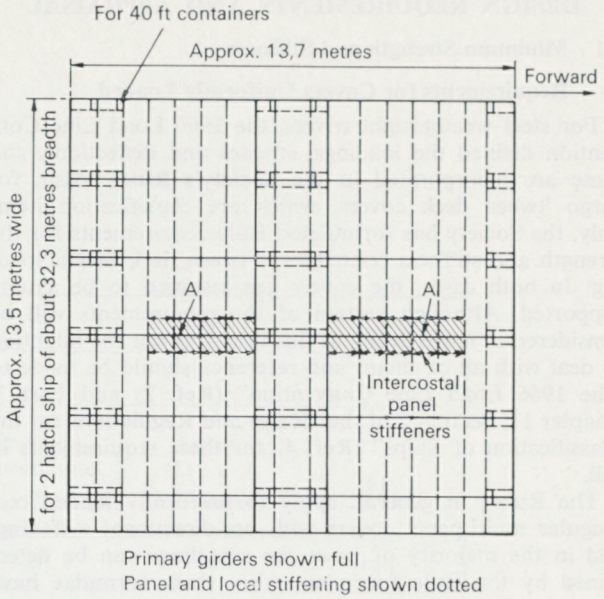


FIG. 9

Typical single piece hatch cover suitable for 3 tiers of containers.

6.4 Plating

6.4.1 Concentrated Loads

The plating of stiffened plate covers has two functions to perform. One is to act as an effective flange of the primary members for the overall bending of the cover, and the other is to provide sufficient strength to resist the loads applied. The first function is important especially from the buckling aspect and this is discussed in para 6.4.3.

The second function is of prime importance, especially when concentrated loads are applied to the cover plating. The capacity of plating to resist concentrated loads, as opposed to uniformly distributed loads, is low. Therefore, local stiffening should be arranged in way of container feet or similar points of concentrated loading.

6.4.2 Wheel-loads

The requirements for wheel loads on hatch covers are given in the Society's Rules, and the scantlings derived from these have proved satisfactory in service.

However, damage can occur to the overhangs at the edges of 'tween and weather deck flush covers where these are insufficiently stiffened. Damage from such a cause can lead to problems with the stowage of the covers, and the opening and closing operations. This aspect should not be overlooked when examining the main panel plating and stiffeners.

6.4.3 Buckling

Figure 10 shows serious buckling which occured in the top plating of multi-panel longitudinally stiffened covers. Requirements to prevent this occurence are now incorporated in the Society's Rules.

However, with the adoption of a higher stress for weather deck covers subjected to container loading, see Table 6, buckling could also be a problem where these are formed from orthogonally stiffened plate fields, and this aspect should be considered.

In such cases the introduction of intercostal panel buckling stiffeners in way of the areas concerned may be sufficient. The typical area where buckling may occur is marked "A" on Fig. 9.

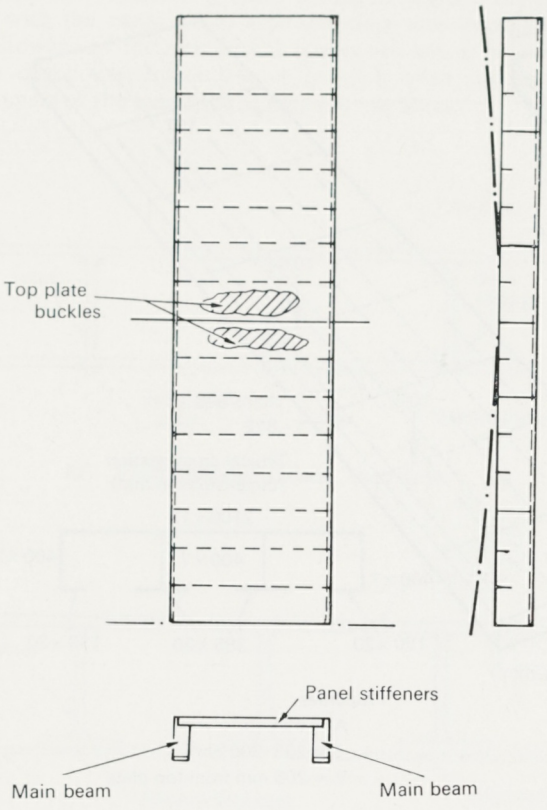


FIG. 10

Buckling of cover top plating.

6.5 Closed Section Hatch Cover Panels

6.5.1 Tests on Models

Tests on models were carried out at Crawley on a hatch cover of open section and a hatch cover of a closed box section (Ref. 6). The covers had the same area eccentrically loaded and a similar section modulus and inertia.

Figure 11 shows the comparison between the two covers, and the deflections and stresses should be noted.

The open section gave a maximum stress of 890 kgf/cm^2 with a deflection of 2.7 cms, while for the closed section the maximum stress is 471.89 kgf/cm^2 and the corresponding deflection is 1.408 cms.

This considerable difference can be accounted for by the greater torsional rigidity of the closed section.

6.5.2 Container point loads

The Society has carried out a study of the distribution of the bending stress across the width of a box girder type hatch cover panel (Ref. 15).

The purpose was to obtain sufficient data and develop a quick calculation method for deriving the scantlings for "Box Type" hatch covers in association with point loads representing container loading.

The curves and derived calculation method are given in Appendix I along with the instructions for their applications.

The study has shown that for a cover panel with the edge adjacent to the cross-joint subjected to point loading, the box girder distributes the load provided there is suitable cleating. This would not be the case with a uni-directional stiffened open panel as, in general, the stiffeners under the point load would require to be of increased scantlings.

The panel should also satisfy the Rule scantlings for uniform loading as explained in para 6.1.

6.5.3 Construction

Figure 12a shows the preferred construction method for constructing box-girder section panels. It should be noted that the one-sided full penetration welds of the closing plates are acceptable where the cover loading is uniform. In cases where the covers are also arranged for carriage of containers, or any other concentrated loading then the penetration welds should be effected on to backing straps in the area of the load points. The arrangement with backstraps would also be suggested to be used throughout in cases where this type of cover is adopted for combination carriers.

Normally the top and bottom plates of a box-girder type panel are of equal thickness. However, some manufacturers have proposed an open-type uni-directional stiffened panel with thin bottom closing plates attached by fillet welds to the bottom face bars of the stiffeners. See Fig. 12b.

In order to eliminate internal corrosion in the box-type girder it is the normal manufacturing practice to introduce a Vapour Phase Inhibitor, commonly referred to by the abbreviation V.P.I. This type of protection has been successfully used for rudders.

6.6 Multi-panel covers with panels of asymmetrical section

Sliding and "roll stowage" type covers, see Figs. 1(f) and 1(g), with panels of asymmetrical section have been in service for a number of years.

Tests have been carried out on board ship (Ref. 7) and tests on models have been carried out at Crawley (Ref. 8).

Until recent years the covers have been used only for the carriage of uniformly distributed cargoes, but container point loads are now being applied to the panels of this type of cover.

This has required the application of a more sophisticated approach and the procedure for this is explained in Appendix 2.

The cover panels in all cases should satisfy the Rule scantling requirements for uniform loading.

Also, efficient local stiffening is to be provided to ensure that the container loads diffuse into the cover panels.

6.7. Hatch coamings and other cover support structure

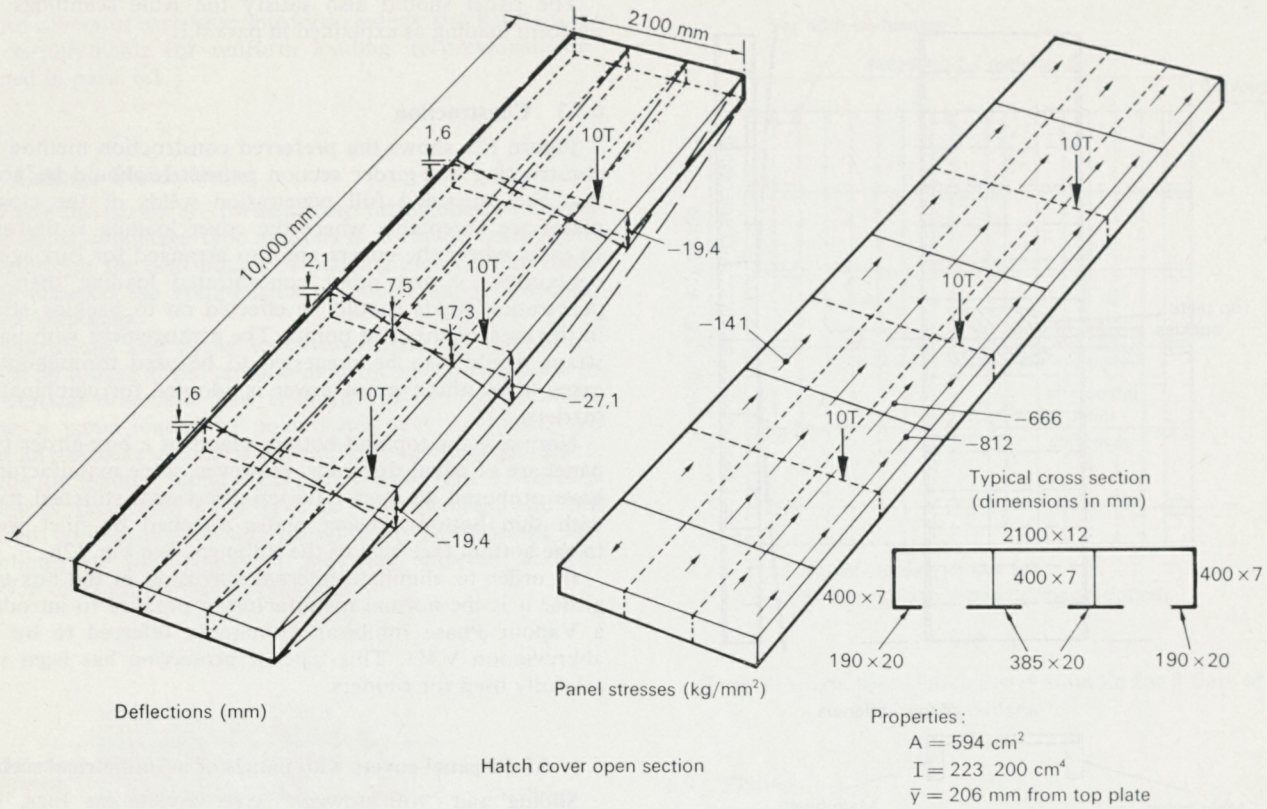
6.7.1 Hatch coamings

The requirements for the heights and scantlings of the coamings for exposed hatchways are given in the Society's Rules. There are no requirements for coamings in 'tween decks within enclosed superstructures, and 'tween deck hatchways can be flush without coamings projecting above the decks.

Hatch coamings can be continuous or non-continuous and ships fitted with either of these arrangements have been successful in service.

The coamings should have sufficient stiffness and rigidity to support the cover and its loading. The requirements for stiffening and arrangement of stays are given in the Society's Rules.

The height of coamings may require to be increased to suit the operation of certain types of mechanical hatch covers, and also as previously mentioned, under Load Line aspects, para 3.4 where this is shown to be necessary by the floatability calculations. In such cases the stiffening and arrangement of stays would be specially considered.



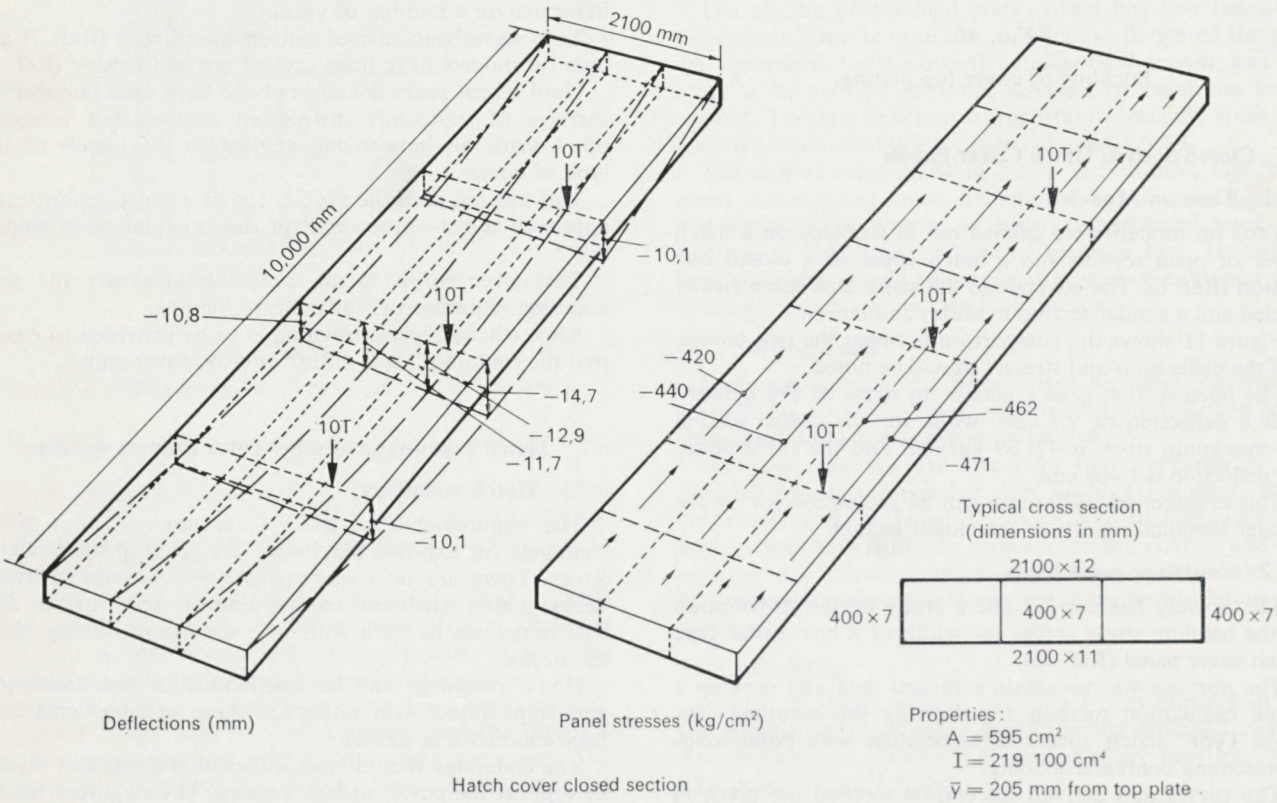
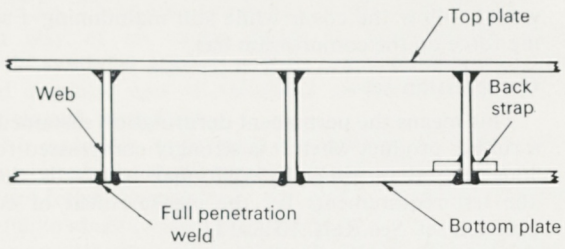


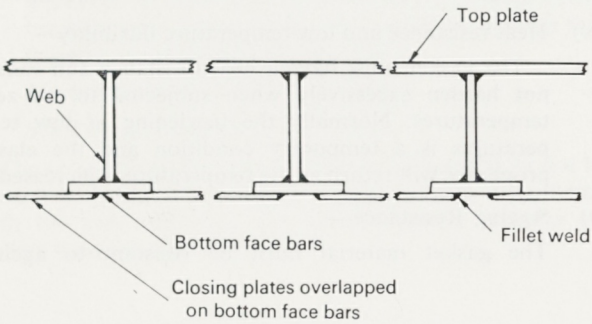
FIG. 11

Comparison between closed and open section hatch cover panels.

Extension brackets or rails arranged approximately in line with the cargo hatch side coamings and intended for the stowage of the mechanical covers are not to be welded to a deckhouse, masthouse or to each other unless they form part of the longitudinal strength members.



(a) Conventional closed "box-type".



(b) Open uni-directional stiffened panel with thin closing plates.

FIG. 12

Construction of closed "box-type" cover panels.

6.7.2 Other Cover Support Structure

In the case of containerships, and certain other wide-hatch ships, the following arrangements are made to keep the size and weight of covers and panels within the practical handling limits.

(a) Fore and aft coamings are fitted intermediate to the normal side coamings. Either one on the centreline, or one port and one starboard, and arranged in line with continuous fore and aft underdeck girders.

(b) The continuous fore and aft underdeck girders referred to in (a) are omitted and non-integrated fore and after hatch beam/coamings are arranged above deck. In some cases these are permanently fixed at one end and simply supported and free at the opposite end, and in other cases simply supported at both ends.

Both of these arrangements would require special consideration to ensure that they are suitable for the proposed cover loading and cleating arrangements. Also, for arrangement (b) that they will not be displaced excessively by the lateral loads due to rolling and the end loads due to pitching, or the hydrostatic loads in way of floodable holds.

6.7.3 Containers and other concentrated load points on coamings and other cover support structure

Where containers, or similar concentrated loads are carried on hatch covers, the hatch coamings in way of the load points will require to be reinforced to resist the lateral loads imposed on the coaming due to the rolling and pitching of the ship. Thrust blocks are to be fitted on the coaming rest bar to prevent the covers from moving. Where single piece covers are fitted with locating devices, the coamings are to be reinforced in way of the locators.

Also the coamings will require to be reinforced to resist any loads normal to the plane of the cover imposed due to the ship motions. These items will be dealt with now in greater detail.

6.8 Reinforcement for the dynamic effects of roll, pitch and heave

6.8.1 Determination of forces on covers and coamings

The inertial forces generated by accelerations due to roll, pitch and heave of the ship can be calculated from the Society's "Guidance Notes, Freight container securing arrangements" (Ref. 9) or by means of the Hewlett-Packard desk-top computer Program.

From these calculations the components of force, normal to deck and parallel to deck may be ascertained. Other programs and methods giving similar answers would be acceptable.

The total weight used in the calculations should include the weight of the cover.

6.8.2 Reinforcement of covers and coamings for the dynamic forces

In covers and panels the side plates are reinforced at bearing areas to allow for the dynamic forces normal to the deck. The acceptable bearing pressure will depend on whether the reinforcement consists of a side plate of increased thickness or a sophisticated bearing pad arrangement, see Plate 13, and can vary from 200 kgf/cm^2 to 600 kgf/cm^2 depending on the arrangement. The coamings or support structure in way should be locally reinforced to carry this load into the hull structure. If possible, consideration should be given to this in the early design stages of the hull structure to obtain an economical and practical arrangement.

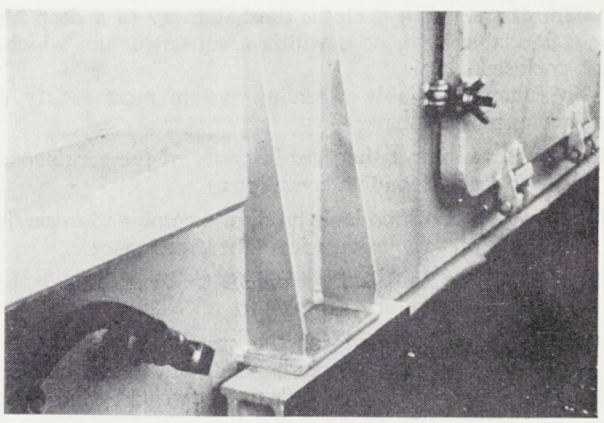


PLATE NO. 13

Cover bearing pad.

The cover top plating should also be reinforced by pad pieces and local stiffening, or equivalent arrangements, in way of these concentrated load points.

Locators or positioning devices are fitted to the coaming rest bars to prevent the transverse and longitudinal movement of the cover. They should be designed to allow for the distortion of the hatchways. In certain cases these

can be arranged to act as the thrust blocks taking the dynamic lateral loads. In such cases the strength of the fittings and their weld attachment must be of sufficient strength to withstand shock loading and the coamings should be locally reinforced in way.

6.9 Materials

In general, mild steel is used for the construction of hatch covers. In some cases with concentrated loadings it may be necessary to resort to the use of higher tensile steel to obtain a reduction in weight. The higher tensile steel is normally adopted for the stiffener face plates, or stiffener face plates and webs and the top plating remains mild steel.

On account of the Rule deflection requirement there is no great advantage in making the complete covers of higher tensile steel for the normal Rule uniform loading.

Aluminium Alloy has been used for covers but the cost can be prohibitive. Also the maintenance and repair aspects could create problems with covers of this material.

A glass reinforced plastic (GRP) cover has been fitted to a ship classed with the Society. Although satisfactory from the strength and stiffness aspects the cover constantly sustained damage at the corners and was replaced by a steel cover.

Therefore it is reasonable to assume that steel will remain the predominant material for the construction of mechanical hatch covers for many years to come.

7. SEALING SYSTEM

It is a requirement of the 1966 Load Line Convention, and the Society's Rules, that an exposed steel weathertight cover shall be fitted with efficient means by which it can be secured and made weathertight. This is usually achieved by a securing and locator arrangement, rubber gaskets, and drainage facilities, and for the purpose of this paper will be referred to as the sealing system.

A 'tween deck hatch cover does not require a sealing system except when it closes the hatchway to a deep tank or a floodable hold, or is within a superstructure which is not enclosed.

To function reliably a sealing system must satisfy the following requirements: —

(a) Preserve the weathertight integrity of the cargo spaces in all sea and loading conditions.

(b) In the case of floodable holds and combination carriers it must prevent leakage from the cargo space.

(c) It must be sufficiently resilient to accommodate hull deformations.

(d) The materials used for the system should be compatible with the cargoes carried, and the design standards suitable for the loads to be carried by the covers.

(e) It must be easy to maintain, and be suitable for all extreme climatic conditions that the ship may experience in its lifetime.

The components of the sealing system will be dealt with now in greater detail.

7.1 Gasket Material

The gaskets used in sealing systems are normally manufactured from natural, synthetic or neoprene rubber, or a combination of these.

In the selection of the gasket material the following properties must be considered: —

(i) Elasticity—

The gasket must be able to withstand alternating loading for a long period and still return to its original shape. This means that with the motion of the ship, when the loading from the cover is released the gasket would follow the cover while still maintaining a sealing force on the compression bar.

(ii) Compression set—

This means the permanent deformation sustained by a rubber product when it is strongly compressed for a long period of time. International standards define the test requirements for the measurement of compression set. See Refs. 10 and 11.

(iii) Tensile strength—

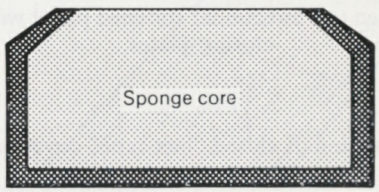
The gasket will be subjected to a combination of compression and stretching, and therefore the tensile strength is important in the selection of the material.

(iv) Heat resistance and low temperature flexibility—

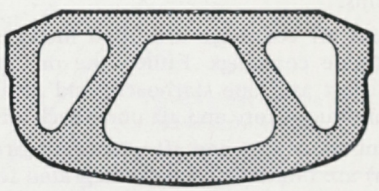
The gasket must have a heat resistance and should not harden excessively when subjected to sub-zero temperatures. Normally the hardening at low temperatures is a temporary condition and the elastic properties will return as the temperature is increased.

(v) Ageing Resistance—

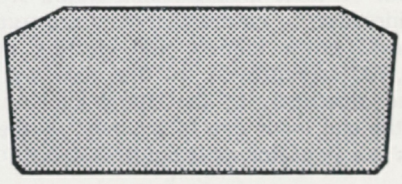
The gasket material must be resistant to ageing.



a) Sponge rubber core with skin



b) Hollow neoprene



c) Solid neoprene

FIG. 13

Main types of gasket sections.

(vi) Resistance to Water and Oil—

The gasket material must have this quality. Natural rubber is resistant to water, while Nitrile, a synthetic rubber is resistant to oil.

Rubber and Neoprene synthetic rubber gaskets have, in general, good heat, ageing, weather and flame resistance qualities but only moderate chemical and oil resistance properties. These are used in way of dry cargo spaces.

In way of oil cargo spaces on combination carriers Nitrile synthetic rubber gaskets are used and these have good chemical and oil resistance properties but poor low temperature properties.

The materials to be used for gaskets of covers on refrigerated ships require special consideration.

For fuller information on gasket material reference should be made to (Ref 10 and 11).

In general, the main types of gasket sections adopted are shown in Fig. 13 and as follows: —

(a) Natural rubber cellular or sponge core with a natural rubber or neoprene skin on three sides (The skin is abrasion resistant and intended to protect the softer resilient core which allows the gasket to deform sufficiently to achieve an efficient seal.)

(b) Neoprene extruded hollow or open.

(c) Solid neoprene section.

The selection of the type and size of gasket should not be treated in isolation but must be considered in conjunction with the type of cover, the sealing system, and the repective hatchway deformations.

7.2 Gasket sealing arrangement

7.2.1 Peripheral Gaskets

For peripheral gaskets the conventional sealing arrangements are shown in Fig. 14, and basically these consist of an arrangement where a compression bar bears against the gasket. A steel to steel contact between the hatch cover side-plate and the coaming bar, or an equivalent arrangement, is essential to ensure that the gasket is not over-compressed, and avoid a permanent set in the gasket. Thus the gasket takes only sufficient load to achieve weathertightness and retains the reserve elasticity referred to previously.

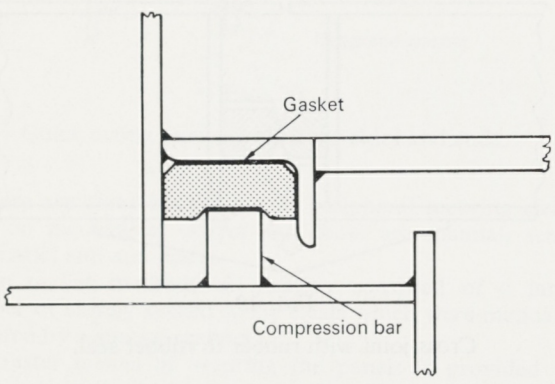


FIG. 14

Conventional peripheral arrangement with rubber gasket.

Some cover manufacturers limit the compression for gaskets of the type shown in Fig. 13 (a) to 25 per cent of the depth of the gasket and this has proved successful in service. This percentage is based on the fact that a permanent "compression set" will not normally occur if the designed area after compression is not less than 75 per cent of the uncompressed cross sectional area of the gasket. This type of gasket is also arranged with sufficient width to allow for any lateral movement of the cover.

However, when a cellular or sponge rubber section is adopted it must be fixed by adhesive into a close fitting retaining channel and this restricts the flexibility in the transverse direction. To overcome this some cover manufacturers developed extruded rubber or neoprene sections. See Fig. 15. The idea is to eliminate the distortion during the closing of the covers, and enable the section to act like a spring and maintain the weathertightness when the covers move with the ship's motions.

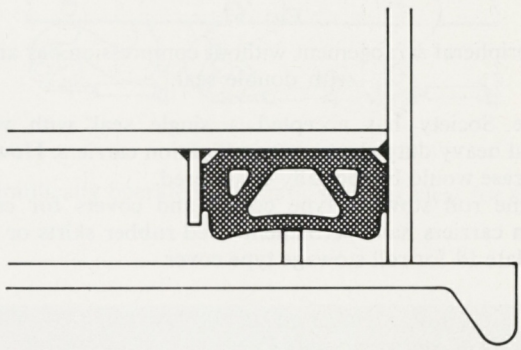


FIG. 15

Conventional peripheral arrangement with hollow neoprene gasket.

With the hatchway distortion problems encountered on "open-type" ships, and the method of obtaining a satisfactory seal to accommodate this, cover manufacturers developed the extruded neoprene section shown in Fig. 16. The compression bar is omitted and the gasket bears on the coaming rest bar. This arrangement permits horizontal as well as vertical displacements while maintaining the weathertightness.

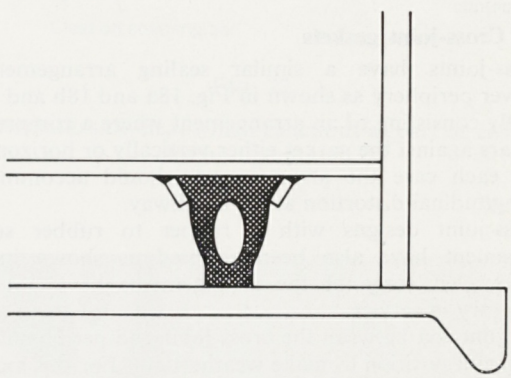


FIG. 16

Peripheral arrangement without compression bar.

Another similar type of section has been adopted for combination carriers to achieve a double seal and this is shown in Fig. 17.

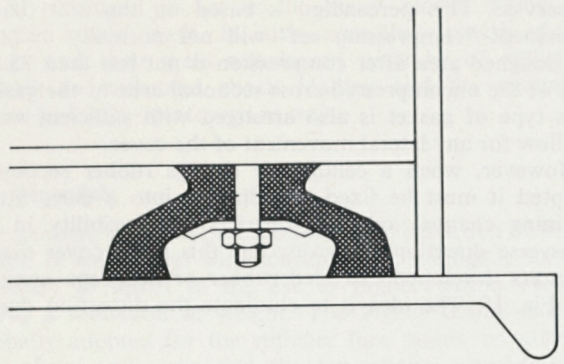


FIG. 17

Peripheral arrangement without compression bar and with double seal.

The Society has accepted a single seal with widely spaced heavy duty cleats on combination carriers. However, each case would be specially considered.

Some roll stowage type covers and covers for combination carriers have permanent fixed rubber skirts or seals. See plate 14 for roll stowage type cover.

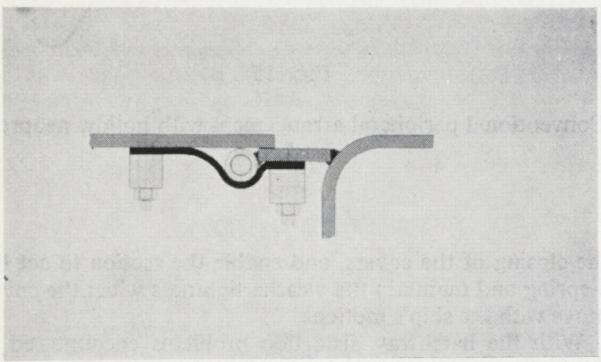


PLATE NO. 14

Permanent rubber seal for roll stowage type cover.

7.2.2 Cross-joint gaskets

Cross-joints have a similar sealing arrangement to the cover periphery as shown in Fig. 18a and 18b and again basically consisting of an arrangement where a compression bar bears against the gasket either vertically or horizontally.

For each case the arrangements should accommodate the longitudinal distortion at the hatchway.

Cross-joint designs with a rubber to rubber sealing arrangement have also been adopted as shown in Fig. 19. However, some of the arrangements have not been satisfactory in service.

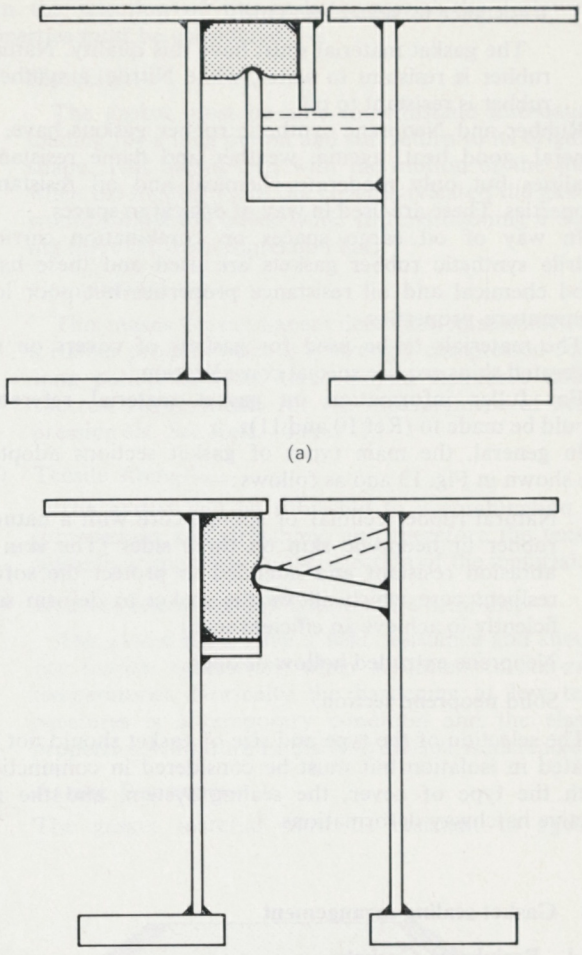
The junction between the cross-joint and peripheral seals is a difficult position to make weathertight. For this location the majority of manufacturers produce specially moulded rubber sections which fair into the cross-joint and peripheral gaskets.

7.3 Securing and Locator Arrangement

An efficient cleating arrangement must allow for the relative movement between the cover and the hatchway without being disengaged by this movement. Also, it must be designed for ease of maintenance, and give satisfactory reliability.

7.3.1 Peripheral Cleating

In designing the peripheral cleating arrangement attention should be given to the holding down force. This is dependent on the type of cover and the loading on the cover. Also in combination carriers allowance should be made for the internal pressure of the cargo spaces as well. In the case of containers and other tall loads allowance should be made where the centre of gravity of the load is outside the line of cover when the ship is assumed inclined at 30 degrees.



(a)

(b)

FIG. 18

Basic cross-joint seals.

(a) Compression bar in vertical direction.

(b) Compression bar in horizontal direction.

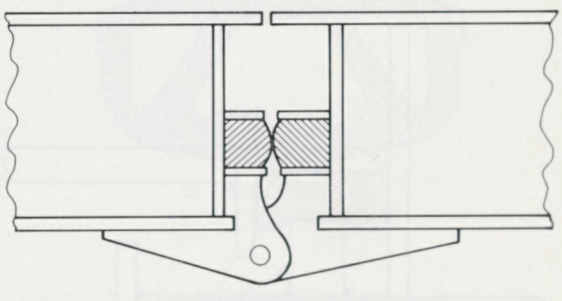


FIG. 19

Cross-joint with rubber to rubber seal.

The arrangement is to be such that cleats having a net cross-sectional area of not less than 2.8 cm^2 are spaced about 2 m apart, with a minimum of two cleats per panel in association with a gasket loading per unit length of 5 kgf/cm. If arrangements are provided for interlocking panels, then one cleat per panel may be sufficient.

Where heavy duty cleats are fitted, their spacing may be increased to a maximum of about 6 m, provided that the net cross-sectional area, in cm^2, of each cleat is not less than 1,4 times the cleat spacing, in metres, in association with a gasket loading per unit length of 5kgf/cm. Where the gasket loading exceeds that given above, the net cross-sectional area of each cleat is to be increased in direct proportion to the loading. Cleats are to be arranged as close as possible to hatch corners.

The spacing and size of cleats or other securing arrangements on hatch covers for holds in combination carriers would be considered in relation to the calculated edge forces and proposed gasket arrangements.

The cover edge stiffness is to be examined in order to ensure continuing compression between gasket and compression bar along the full length. The inertia of the cover edge (I_E) is to be not less than :—

$$I_E = 6W_1S_1^4 \text{ cm}^4$$

where W_1 = the gasket loading per unit length, in kgf/cm, but not less than 5 kgf/cm,

S_1 = spacing of cleats, in metres.

An example of a direct calculation method is shown in Appendix 3.

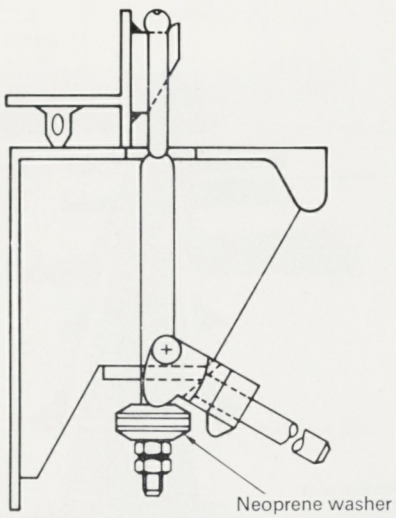


FIG. 20

Quick acting securing cleat for sides and ends.

There are three basic types of peripheral securing cleats used on mechanical covers and these are manual, semi-automatic, and automatic.

The earlier methods of cleating consisted of a large number of closely spaced screw cleats which were manually operated by a special spanner.

A faster means of securing the panels is provided by quick acting cleats as shown in Fig. 20. These are operated manually by means of a special lever acting on a "up and over" principle. The amount of compression provided by this arrangement is pre-set by means of the neoprene washers so that the loading is shared evenly to all cleats to prevent them being over-tightened. The neoprene washers also add resilience to the cleats and prevent them from being too positive and breaking.

Securing may also be achieved by means of a completely automatic cleating device as shown in Fig. 21. This arrangement can assist in a quick cargo turn around, and with a minimum of shipboard personnel involvement. The cleating is operated by a motorized or manual hydraulic pump. When hydraulic securing is arranged, a means of mechanical locking in the event of hydraulic failure would be required. Also where certificates are specifically requested the piping is to be tested to a pressure not less than 1.5 times the working pressure.

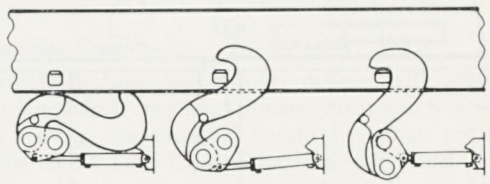


FIG. 21

Hydraulically operated automatic securing cleat for sides and ends.

There are also automatic peripheral cleating devices which function as part of the closing operation of the cover and Fig. 22 and Plates 5 and 15 show examples of these.

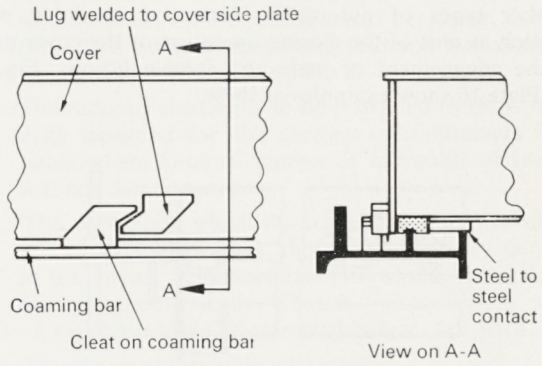


FIG. 22

Automatic side cleat which functions as part of cover closing operation.

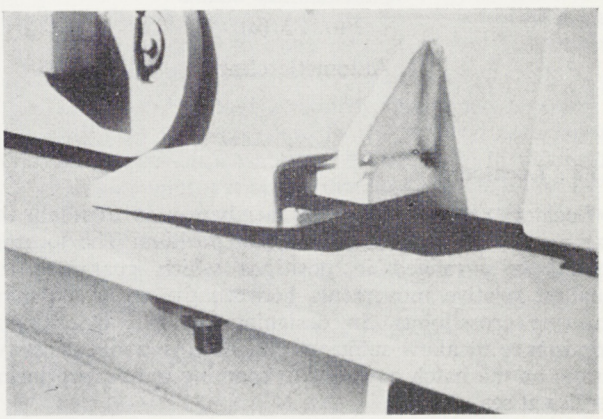


PLATE NO. 15

Automatic peripheral cleat for a roll stowage type cover.

7.3.2 **Cross-joint Cleating**

Cross-joint securing and sealing arrangements are also extremely important. The arrangement of cleats is to be such that the cross-joint wedges are to be spaced not more than 1.5 m apart. Alternatively, where positive securing devices are used these can be accepted about 3 m apart.

The cleats can be in the form of manually operated wedges, see Fig. 23a, or manually operated screwed cleats.

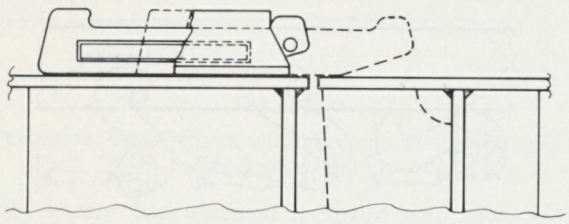


FIG. 23 (a)

Typical wedge cleat.

Automatic cleating arrangements are also available where a torsion bar fitted between each panel is activated by the cover closing operation and closes the cleats. There is also a similar type which is manually operated from a wheel at the side of the cover. Fig. 23b shows an example of this.

Other types of automatic cleats are available which function as part of the closing operation of the cover panels by the engagement of male and female fittings. Fig. 23c and Plate 16 show examples of these.

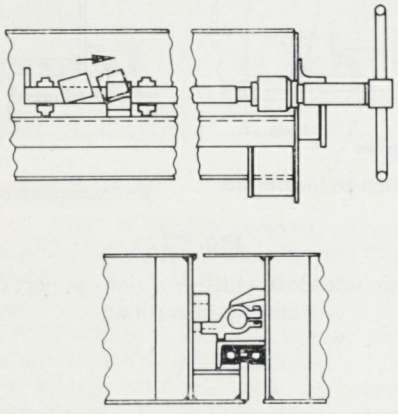


FIG. 23 (b)

Automatic cleat.

7.3.3 **Locators**

Locators are the fittings or members used to retain the hatch covers in the correct sealing position. The locators should be arranged in positions which guarantee the smallest relative movements between the cover, coaming and the cross-joints. In designing these it is of great importance to allow sufficient clearance to avoid excessive forces on the hatch covers with coaming movement during service at sea.

Where the covers are designed to carry containers and heavy loading the strength of the fittings should be suitable for the additional dynamic loading and this has been discussed already in para. 6.8.2.

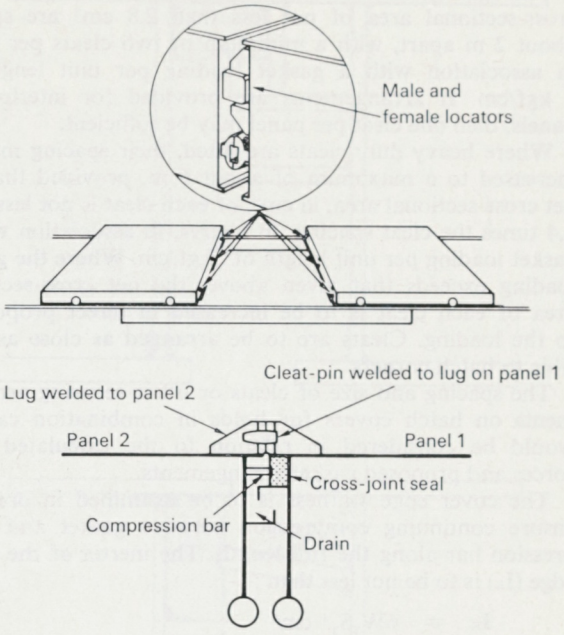


FIG. 23 (c)

Male and female locator.

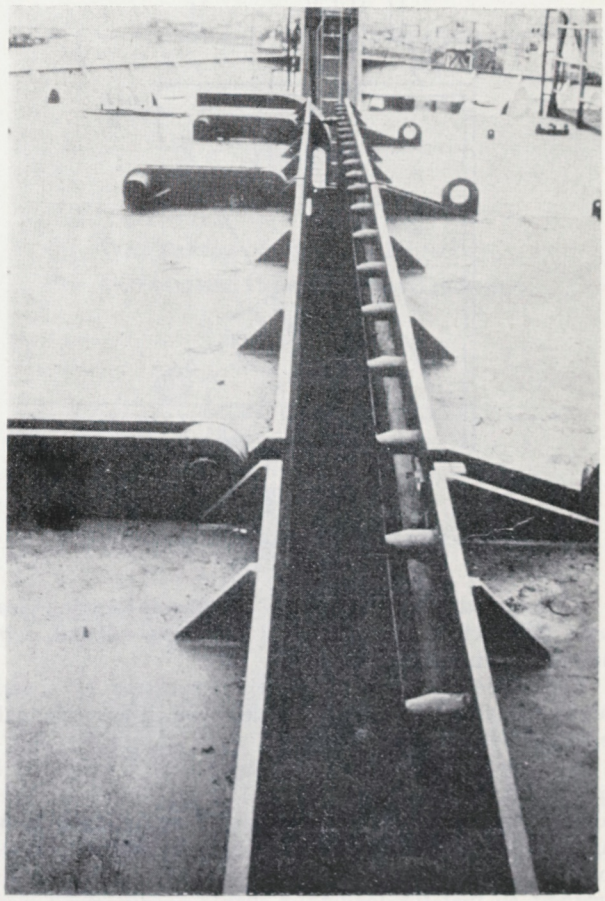


PLATE NO. 16

Male and female locators for two piece side rolling covers.

7.3.4 Tank Hatch Covers in 'Tween Decks

The maximum spacing of cleats on tank hatch covers in 'tween decks is to be 600 mm, but cleats are to be arranged as close as practicable to the corners.

Alternative proposals would nevertheless be specially considered.

7.4 Drainage

Experience has shown with the operation of mechanical steel hatch covers that the provision of drainage is very important and serious consideration should be given to this aspect in the initial design stages.

Figure 24 shows an arrangement which is commonly referred to as single drainage. The drainage channels are sealed by means of the gaskets and compression bars which provide the only weathertight protection. Any sea water which penetrates the gap between the coaming bars and skirt plates with the movement of the ship, is drained away along the drainage channels and out to the deck through small holes arranged in the skirt plates or coaming rest bar. Similarly, any water which enters the cross-joint drainage channels is drained away to the deck through holes at the sides of the cover.

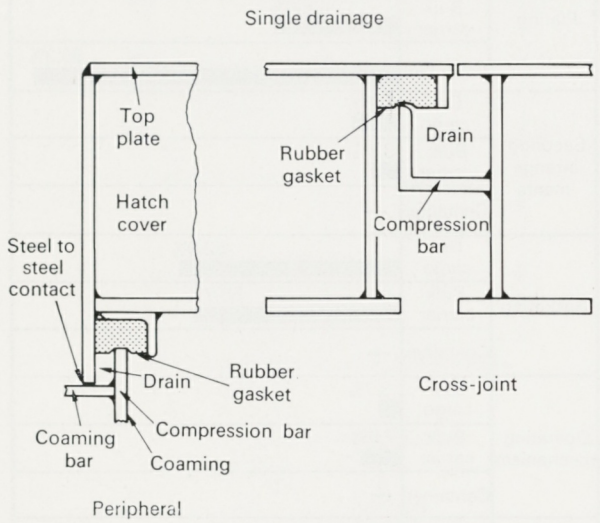


FIG. 24

Sealing system with single drainage.

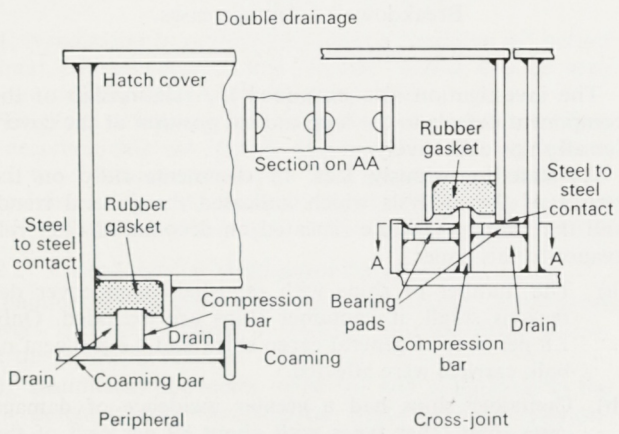


FIG. 25

Sealing system with double drainage.

Hatch cover designers have refined this arrangement with the provision of a second drain channel arranged with a non return valve or equivalent arrangement. This ensures that any sea water passing the gasket is drained away through the drain valve in a similar fashion to that in single drainage. The design of the drain valve is important and is to be specially considered. This arrangement is referred to as double drainage and is shown in Fig. 25.

These arrangements also assists to prevent the entry of entrapped water and condensate as the covers are being opened.

7.5 Special Cases

Weathertight steel hatch cover designs with special sealing arrangements, insulated covers, flush hatch covers, and covers having coamings of height less than required by the 1966 Load Line Convention and the Rules are to be specially considered and should be referred to Headquarters for guidance at the initial design stage.

7.6 Container Ships

In certain cases a reduced hatch cover securing arrangement can be accepted on container ships provided the following aspects are considered and confirmed.

(a) Consideration can only be given to reduced cleating for one piece hatch covers as generally fitted.

(b) The minimum securing arrangement of the covers would usually be four token cleats per cover, normally fitted two on each transverse coaming but alternative arrangements will be considered.

(c) The reduced cleating is to be restricted to ships specifically designed for the carriage of containers in the holds where minimal ingress of rainwater or seawater will not damage cargo.

(d) The deck upon which the hatch coamings are situated are at least 4.6 metres above an imaginary deck line at the virtual depth necessary to obtain the scantlings draught geometrically. That is the equivalent of two tiers of superstructures of standard height. See para. 6.1.

(e) The covers are suitably gasketted.

(f) Confirmation that the container stowage and lashing arrangements will not impose a lifting force on the hatch cover edge with the ship listed to 30°.

(g) Positive arrangements are provided to locate the limit of the movement of the hatch cover on the hatch coaming.

(h) The Owner is aware that the Society's Surveyors will not be required to carry out a hose test for weathertightness on the hatch covers.

(j) That the National Authority concerned is aware of and give their approval to the reduced securing and subsequent dispensation of hose testing. In this respect the plan approval centre involved should advise I.C.D. (Loadline) of the action taken to obtain National Administration approval.

Also in some of the third generation ships gaskets were omitted and agreed to by the National Authorities concerned on account of the high freeboards and following model tests for deck wetness.

7.7 General

The sealing system is the means for maintaining the weathertightness and integrity of the cargo space, and in the selection of the system the compatability of the various

components must be examined together in relation to the type of cover, and hatchway deformation.

The designers' tolerances for the dimensions, shape, operating mechanisms and coamings should also be established and taken into account when the sealing system is considered. This is to confirm that the design compression allowance of the seals will cater for extreme values of these tolerances, otherwise the "as-fitted" compression of the gaskets may be inadequate.

It can never be over emphasised that a "too positive" cleating arrangement can lead to problems in service and every endeavour should be made to obtain a resilient peripheral and cross-joint cleating arrangement.

Also the importance of an efficient drainage arrangement must never be overlooked.

8. DEFECTS IN SERVICE

8.1 Statistical Records

The Society has a wealth of data on classed ships which is stored in the data bank and maintained by the Technical Records Department. This was the subject of another paper presented to the Technical Association this session (Ref. 12).

From these statistical records information regarding any apparent preponderance of reported defects is fed back to the proper department. If it is considered necessary, action is taken by formulating new requirements or recommendations to prevent or reduce the recurrence of these defects.

In the case of 'tween deck cargo hatches the damages have on the main been attributable to cargo damage, wear and tear, and over-loading.

In connection with weather deck hatchways the Technical Records Department has carried out an extensive statistical study of reported defects on dry cargo ships, bulk carriers, and container ships built to the Society's class during the period between 1966 and 1975 inclusive and having a Rule length of 100 metres or greater (Ref. 13). The total years of service covered the period from January 1966 to May 1976 and for the purpose of the study, the incidence of the damage cases was calculated as the ratio of the number of reported damage cases per one hundred ship years of service.

The results of the study have been fully commented on in Ref. 14, but it is considered relevant and important to refer to certain points again at this time.

As mentioned previously the mechanical hatch cover installation must be considered in its entirety. Therefore, any analysis of the defects should relate to all the components that preserve the weathertightness.

From the initial breakdown of damage cases shown in Fig. 26 it is indicated that about 20 per cent of all defects were due to cargo handling, while the other 80 per cent were attributable to heavy weather, wear and tear, or unknown causes. This breakdown does not indicate the extent or the severity of the damage, but does show that container ships have by far the highest incidence of damage cases overall.

A more detailed breakdown of damage cases attributable to causes other than cargo handling is also shown in Fig. 26. This relates to the cover components and would indicate that dry cargo ships and bulk carriers have similar components with the gasketing accounting for about 50 per cent of all defects, and plating for about 25 per cent. In the case of container ships, about 90 per cent of all defects involved the plating.

The influence of speed was investigated and the analysis indicated that this was not a factor influencing the incidence of hatch cover defects.

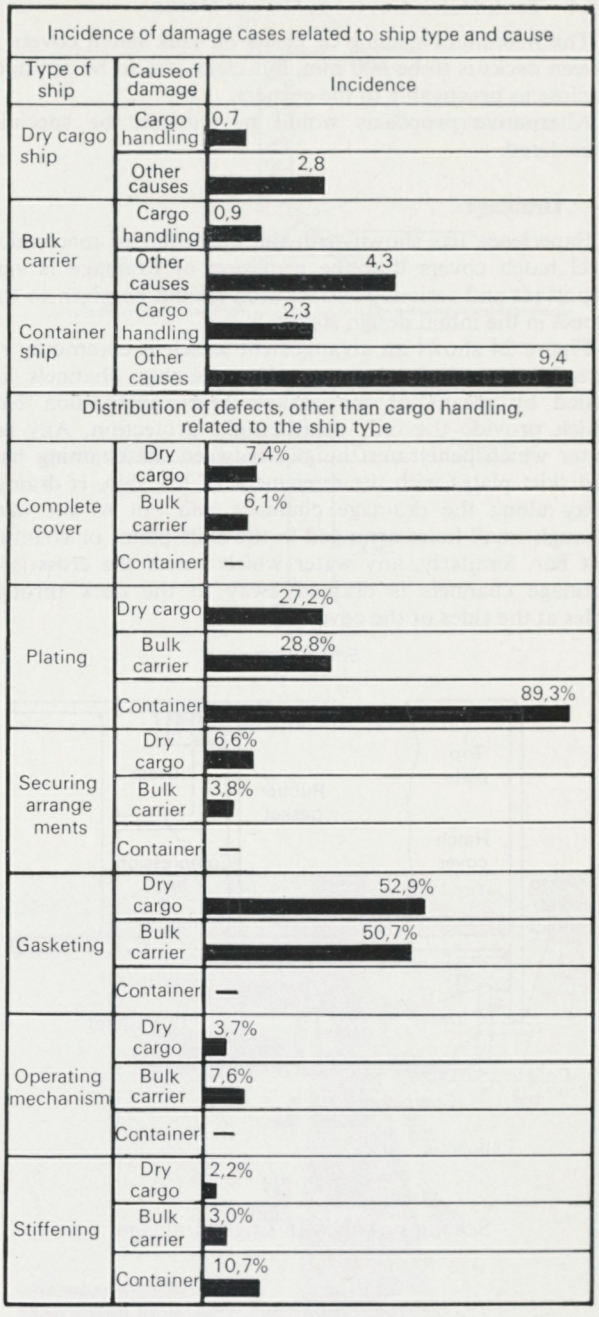


FIG. 26

Breakdown of damage cases.

The investigation also examined the relationship of the component defects to the longitudinal position of the covers for all ships collectively.

As stated previously Ref. 14 comments fully on the results of the analysis which indicated the general trend, and the main points are repeated on account of their relevance to this paper.

(a) The number of ships with reported hatch cover defects is small, if container ships are excluded. Only 2.8 per cent of general cargo ships and 4.3 per cent of bulk carriers were affected.

(b) Container ships had a greater incidence of damage cases than other types with about 89 per cent of the damage involving the plating. This could be accounted for by the fact that the covers are normally single

panel type carrying concentrated loads. Also hatchway distortion is likely to be greater on a container ship than on other types of ships.

(c) In dry cargo ships and bulk carriers the gasketing defects were found to account for 50 per cent of the recorded defects.

(d) The majority of damage to cover plating is likely to occur at the forward end. Also the position of erections can influence the possibility of damage. Midship erections offer more protection against damage to hatch covers.

(e) Damage to operating mechanisms is most likely to occur at the ends of the ship, and in ships with machinery aft can be expected to be worst at the aft end hatches.

8.2 Types of Defects

8.2.1 Container Ship Single Piece Covers

Fractures occurred in the side plates of early designs of covers and these are shown in Fig. 27. These were associated with areas of excessive bearing, and in some of the later designs the side plates were reinforced at selected bearing areas.

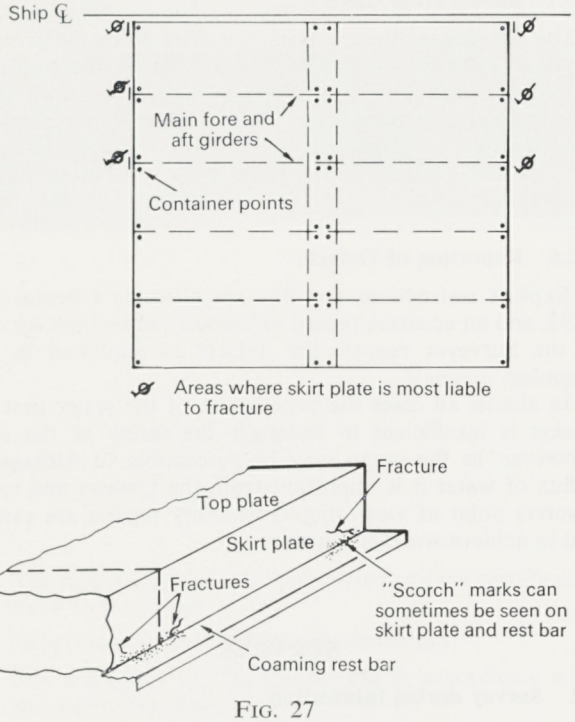


FIG. 27

Fractures in containership single piece covers.

It is indicated from experience that a "bedding in" period should be anticipated and "scorch" marks can be seen on the coaming rest bar during this period.

This type of damage will be high unless means are taken to accommodate the friction between the cover side plates and the coaming rest bars. The adoption of sacrificial aluminium strips on the coaming rest bars have assisted in the prevention of this type of damage. See also para 5.4.

8.2.2 Cross-joints of Multi-panel Covers

Failure of the cross-joint seals in exposed multi-panel covers is a major cause of leakage into the cargo spaces for the following reasons.

(a) Insufficient allowance made for hull elongation in the design stages. Also, that an unloaded panel adjacent to a panel loaded with container point loads can maintain a weathertight seal because of the greater deflection of the loaded panel.

(b) Unfairness or curvature of the compression bar caused during fabrication of the covers.

(c) Impact damage from cargo.

(d) Damage caused by entrapping wires or other abrasive material during closing operations.

(e) The condition of the gasket material, its resilience, and if wear and permanent grooving is apparent. Plate 17 shows an example of this.

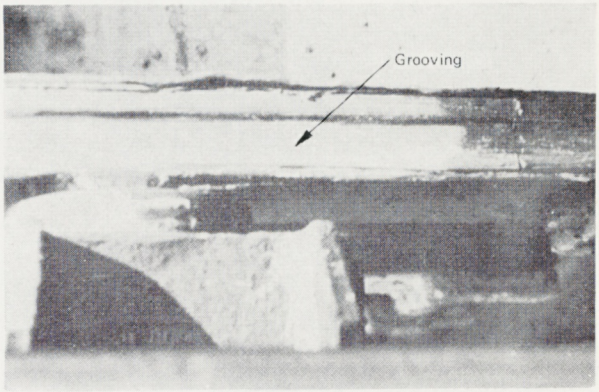


PLATE NO. 17

Wear and permanent grooving of gasket.

(f) Renewal of gaskets with gaskets of wrong size.

(g) Wear down of wedges and housing, and sometimes lack of stiffening brackets under cover plating overhang in way of wedges. Also difficulty in securing cleats and wedges through misalignment of adjoining panels.

(h) Accelerated cross-joint corrosion due to blockage or partially blocked drain holes. In particular the corrosion of the compression bar.

(i) Wear on linkage hinge or locators causing misalignment and impossibility of achieving proper seal.

(j) Condition of rolling wheels, tracks etc. of the operational fittings which can prevent closure and cause misalignment of the panels. Plates 18 and 19 show typical examples of this.

(k) Rubber to steel sealing arrangement without a compression bar (see Fig. 28). After a period of time in service it may be necessary to fit a compression bar at the toe of the drainage angle to achieve weathertightness. Care is needed or else (b) will occur.

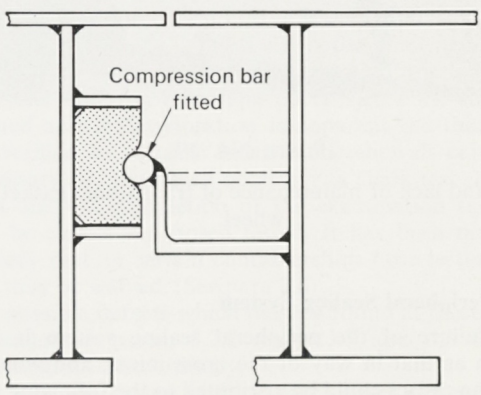


FIG. 28

Cross-joint with ordinary angle compression bar.

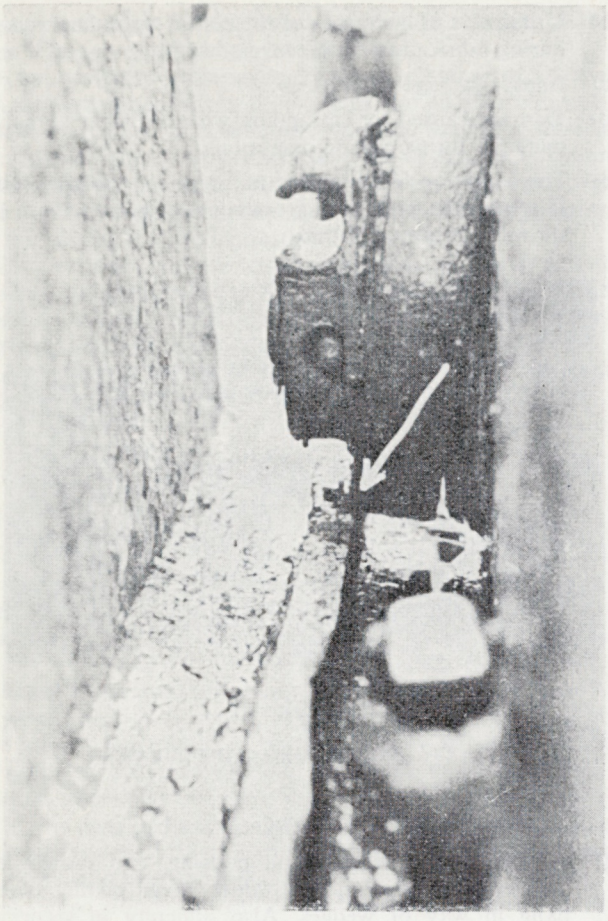


PLATE NO. 18

Rolling wheel and damaged track.

PLATE NO. 19

Wear and lack of maintenance of transitional gasket, and wheel.

8.2.3 **Peripheral Sealing System**

The failure of the peripheral sealing system is not as common as that in way of the cross-joints, and where this occurs the causes could be attributed to the following: —

(a) Cleats which are "too positve", lack resilience and break.

(b) Careless handling of covers and the operational mechanisms.

(c) The condition of the gasket material.

(d) Faulty renewals of the gasket materials.

(e) Insufficient allowance made for lateral distortion of hatchway in the design stage. See also para. 4.4.

(f) Scoring of coaming compression bar from cargo runner.

(g) Wear in rollers, wheels, tracks etc. of operational fittings, and insufficient maintenance of these items.

(h) Omission or wrong positioning of locators.

(i) Wear and tear and cargo damage to cleat housing.

8.2.4 **Plating and Webs**

Although the general scantlings are adequate, the average thickness of the plating and webs of stiffening members are approx 7.5 mm. If this is not maintained regularly the diminution in thickness will result in reduced local, and general strength.

8.2.5 **Ballast Hold Covers**

Overloading of these covers can arise from the creation of over pressure or under pressure within the holds by employing high capacity pumps in association with inadequate venting arrangements. Plate 20 shows an example of the "tent-like" collapse for a cover following the creation of a partial vacuum in the hold during the pumping out operation.

8.2.6 **Reporting of Defects**

Explicit instructions for this are given in Circular No. 2293, and an accurate record of defects can be built up only if the Surveyor reports the defects as requested in this Circular.

In almost all cases the penetration of the water past the gasket is insufficient to endanger the safety of the ship. However, as the cargo may be susceptible to damage by influx of water it is important from the Owners and cargo insurers point of view, that satisfactory repairs are carried out to achieve weathertightness.

9. SURVEYS

9.1 **Survey during fabrication**

The normal procedure is for the hatch covers to be constructed by the designers in their own establishment, or for the construction to be subcontracted by them to an outside firm. This would appear to be governed by their production schedule.

The subcontractors are not always experienced in steel fabrication to Classification requirements and this can create problems for the surveyor. On more than one occasion surveyors have found themselves visiting workshops where attempts were made to fabricate large cover panels with the panels resting on a few old bricks. Also with the steelwork and welding facilities available, and the quality of welding and workmanship, it was obvious that the end product would be unsatisfactory.

Therefore, initially the surveyor must satisfy himself, with the facilities and quality of workmanship, and the supervision and quality control in the workshop, that the firm is capable of manufacturing a satisfactory product.

When this has been established the surveyor should pay frequent visits to the workshop to confirm that:—

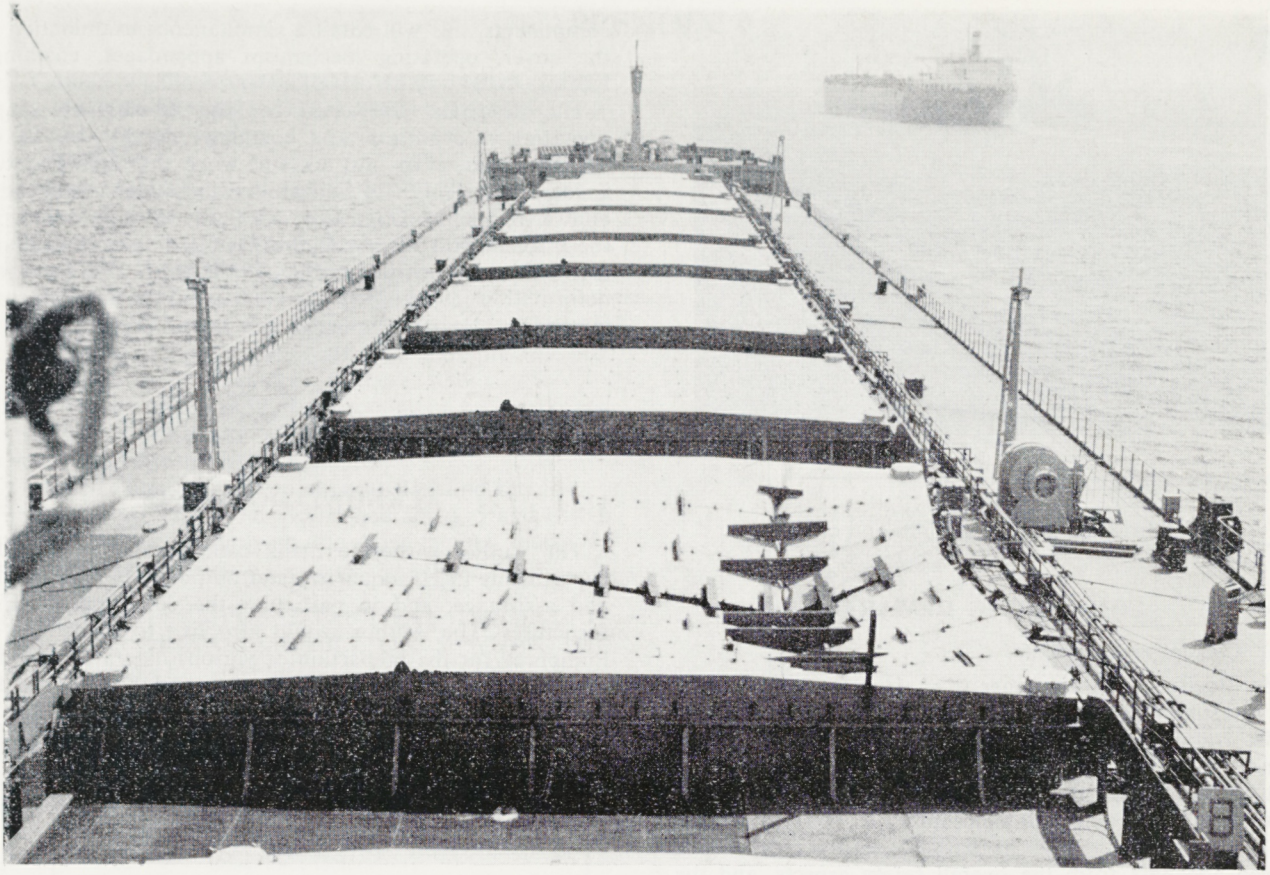


PLATE NO. 20

Vacuum damage in way of a ballast hold.

(a) The steel being used has been tested and the certifficates have been sighted.

(b) Workmanship and welding is satisfactory.

(c) The scantlings and weld sizes are in accordance with the approved plans.

(d) The structural elements are free from weld distortion, especially the skirt plates, retaining angles for the gaskets and the compression bars.

(e) Any local stiffening shown on the approved plans, support brackets in way of cross joint wedges, drainage bars etc. has been fitted.

Plate 21 shows a hatch cover and coamings prefabricated as a unit. This is not always the panacea for hatch coaming unfairness, as the erection and welding of the unit on board ship can present fit-up problems resulting in unfairness of the coaming rest bars.

9.2 Survey during installation aboard

The fitting of the covers to the coamings is normally carried out by the shipbuilder, although the Surveyor should satisfy himself that this has been achieved by the shipbuilder without the necessity of having to resort to the adoption of small packing pieces in way of the gaskets at the periphery and cross-joints. The Surveyor should also witness a satisfactory hose test and confirm that the cleating arrangement is in accordance with the approved plans and is satisfactory.

9.3 Survey in service

For Annual and Periodical Classification surveys the Surveyor must satisfy himself as to the efficient condition of the means of ensuring the weathertightness of the exposed steel hatch covers. The cover steelwork should be examined and if deterioration is apparent the thickness is to be verified by suitable means and renewals carried out as necessary. If considered necessary, a chalk test should be carried out. On completion of the examination the covers are to be closed and hosed tested. It has been mentioned previously that on certain containerships hose testing of the covers may be waived. (See para 7.6).

The possible defects which may be found at these surveys are detailed in paras. 8.2.2 and 8.3.3 and the Surveyor should be guided accordingly.

Any apparent design fault or hatch cover structural fault should be referred to Headquarters with full details and sketches.

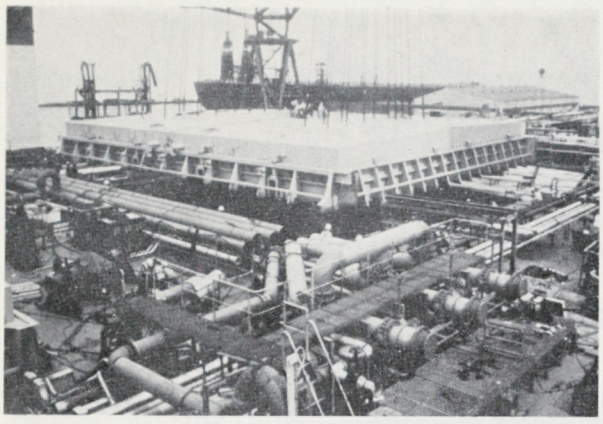


PLATE No. 21

Prefabricated hatch coamings and cover.

10. CONCLUDING REMARKS

10.1 Current requirements

Mr. Buchanan, in his paper (Ref. 1), stated that during the investigation which the Load Line Committee made whilst framing the freeboard rules at that time, it was found that failure of hatches was the cause of thirteen per cent of the vessels lost at sea. This was still in the days of wooden covers and portable beams.

The present standards of strength and stiffness have proved adequate from the overall safety aspects, and the adoption of steel weathertight covers secured by gaskets and cleats reduced the number of serious casualties at sea through hatch cover failures.

Rule parameters for strength and stiffness of hatch covers introduced for container point loading have also proved satisfactory from the experience with ships in service.

10.2 Weathertightness

Although the overall safety aspects are adequate, there are reports of damage to cargo through the ingress of water. Shipowners and insurers have expressed concern about the number and size of insurance claims resulting from this. It is our responsibility as Classification Society Surveyors to ensure that the leakage is reduced to a minimum.

The leakage is more common in older multi-panel hatch cover installations and, in most cases, is attributable to defective seals.

It can be deduced from the Society's statistics and experience that the packing and jointing accounts for about 50 percent of all damages, and the majority of these are in way of the cross-joints.

At all surveys, therefore, the Surveyor should pay particular attention to the condition of gaskets and gasket retaining bars at cross-joints. Also, if gaskets are renewed, it is important that they are the correct size and material. The importance of these renewals should be emphasised to the repairers or shipboard personnel, so that they are not treated in a routine manner.

10.3 Initial design and appraisal

The mechanical hatch cover installation is to be considered in its entirety in relation to the coamings and hull structure. In order to achieve compatibility of the various components, this will entail a simultaneous examination of the cover, operating mechanism appendages, coamings, locators, hatchway deformations and sealing system.

The designers' tolerances for the dimensions, shape, operating mechanisms, and coamings should also be established and taken into account when the sealing system is considered. This is to confirm that the design compression allowance of the seals will cater for extreme values of these tolerances; otherwise the "as-fitted" compression of the seals may be inadequate. Similarly, if the hatchway deformations are ignored, the covers may be unsatisfactory in service.

11. ACKNOWLEDGEMENTS

The Author wishes to thank colleagues in the various departments in Headquarters and outports for their advice and assistance, and in particular the colleagues in Hull Structures. The Author would also like to thank Mr G. Pumphrey for the prepartion of various diagrams included in the paper and Messrs McGregor and Kvaeverner for supplying photographs and information.

The Author has used some illustrations and information from lectures given by Mr R. G. Lockhart and thanks him for his permission.

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APPENDIX I

13. CALCULATION METHOD FOR "BOX-TYPE" HATCH COVERS WITH POINT LOADS

13.1 Procedure

In order to determine the actual distribution of bending moment across the width of cover, at the centre of a box-type hatch cover, loaded with point loads, first calculate the bending stress using the simple beam theory. Then calculate the value of the aspect ratio of the "Leaf".

From Fig. 30 lift off the values of "Stress factors" for the six positions across the width and multiply the previously calculated bending stress by these factors.

Similarly the distribution of deflection can be determined from Fig. 31 "Deflection factors" in association with the inertia and the steel elastic modulus.

A worked example is shown in paras. 13.2 and 13.3.

The shear forces can be ascertained for 4, 5 and 6 web arrangements by multiplying the S.F. factors shown in Fig. 29 by the total load on the cover.

IT MUST BE EMPHASIZED THAT THESE CALCULATIONS ARE APPLICABLE ONLY WHEN THE COVERS HAVE ADEQUATE CLEATING PARTICULARLY AT THE TWO CORNERS REMOTE FROM THE LOAD. THE INVESTIGATION INDICATED THAT THESE CORNERS WOULD LIFT IF NO RESTRAINTS ARE APPLIED. The pull in these corner cleats can also be determined from Fig. 29.

	Shear force factors (Shear force = Total load on 'Leaf' × Shear force)		
	4 Web type	5 Web type	6 Web type
Web No.	4 3 2 1	5 4 3 2 1	6 5 4 3 2 1
1	0,42	0,41	0,40
2	0,14	0,13	0,12
3	0,08	0,07	0,06
4	−0,10	0,05	0,05
5		−0,10	0,03
6			−0,10

FIG. 29

Shear force factors.

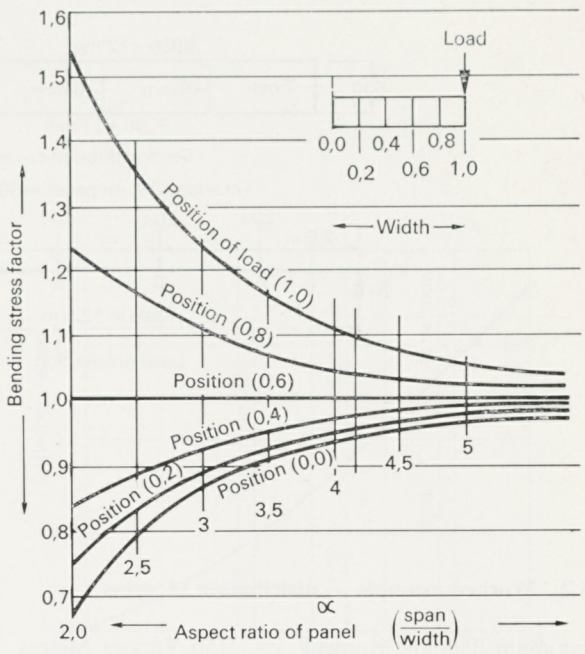


FIG. 30

Stress factors.

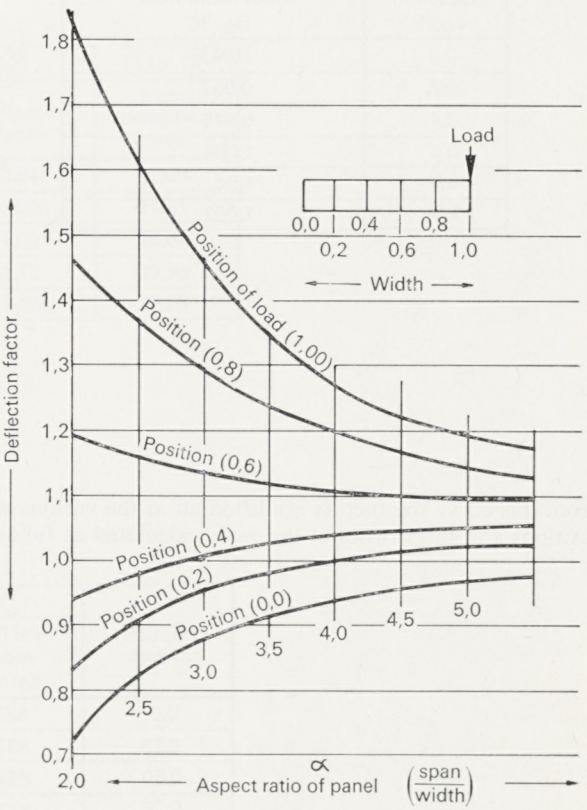
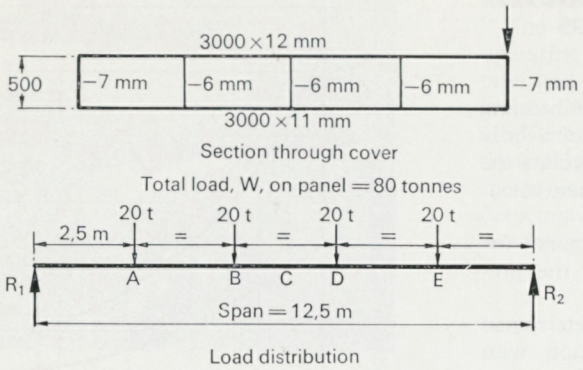


FIG. 31

Deflection factors.



$Z = 17{,}912\ cm^3$
$I = 484{,}040\ cm^4$
$E = 21 \times 10^6\ Tonnes/m^2$
$\alpha = \frac{12{,}5}{3{,}0} = 4{,}167$
$W = 80\ Tonnes$

FIG. 32
Properties.

13.2 **Worked example — distribution of stress**

Maximum Bending Moment = 150 Tonnes Metres
Corresponding mean stress (Based on Minimum Z) = 837 kgf./cm²

From Fig. 20 the following stress factors are lifted off and plotted. See Fig. 33.

Position in width	Stress factor from Fig 30
0,0	0,943
0,2	0,957
0,4	0,975
0,6	1,004
0,8	1,04
1,0	1,092

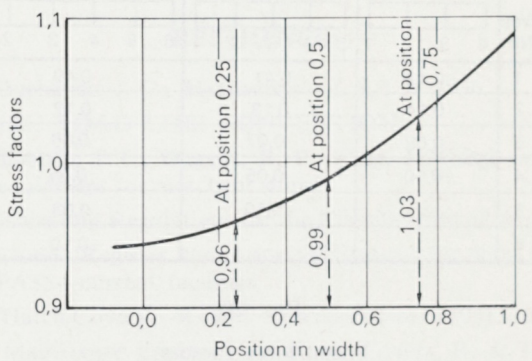


FIG. 33
Plotted stress factors.

From this curve the factors are lifted off at the various web positions and the stresses at the webs calculated as follows:

Position of web	① Initial mean stress Kgf/cm²	② Stress factor	① × ② Mean stress Kgf/cm²
0,0	837	0,943	789,3
0,25	837	0,96	803,5
0,50	837	0,99	828,63
0,75	837	1,03	862,1
1,00	837	1,092	914,0

13.3 **Worked example—distribution of deflection**

Mean deflection at mid span, position C. $= \dfrac{0{\cdot}01575\ Wl^3}{EI}$

$= 24{\cdot}09$ mm

From FIG. 31: The following deflection factors are lifted off and plotted.

Position in width	Deflection factor from Fig. 34
0,0	0,94
0,2	1,004
0,4	1,03
0,6	1,104
0,8	1,185
1,0	1,255

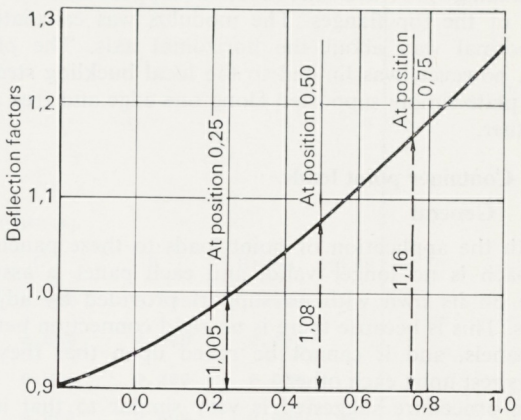


FIG. 34

Plotted deflection factors.

From this curve the factors are lifted off at the various web positions and the deflections at the webs calculated as follows:

Position of web	① Initial mean deflection mm	② Deflection factor	① × ② Mean deflection mm
0,0	24,09	0,94	22,65
0,25	24,09	1,005	24,21
0,50	24,09	1,08	26,02
0,75	24,09	1,15	27,95
1,00	24,09	1·255	30,23

APPENDIX 2

14. COVERS WITH PANELS OF ASYMMETRICAL SECTION

14.1 Uniformly distributed loading.

It has been mentioned already in the main text of the paper that panels of asymmetrical section have been in service for a number of years; and were used for a uniformly distributed loading. With this type of loading it was assumed that the adjacent panels in conjunction with the loading provided an effective support for the free edges of the top flanges. The modulus was calculated in the normal way about the horizontal axis. The plating stress, however, was limited to the local buckling stress of a flat plate simply supported along one edge and free along the other.

14.2 Container point loads.

14.2.1 General

With the application of point loads to these panels this approach is no longer valid, and each panel is assumed to be on its own with no support provided by adjacent panels. This is because there is no rigid connection between the panels, and it cannot be relied upon that they will always rest upon each other.

The procedure suggested is very similar to that in use for conventional hatch covers, except that unsymmetric bending has to be considered.

14.2.2 Procedure

For assessment of the scantlings the first thing which must be done is to calculate the position of the centre of area of the section and Ix and Iy and Ixy about this point. Ix and Iy are the second moments of areas of the section about the x and y axes. Ixy is the product moment of inertia about the x and y axes.

The quantities Ix and Iy can be calculated using the desk-top computer program for section inertias. The centroid can also be extracted from this program. To calculate Ixy the section should be split up into rectangles and the co-ordinates of the centroids of the rectangles calculated. The product moment of inertia, Ixy, can then be calculated using the rectangle's area and co-ordinates.

$$Ixy = \Sigma A.\, y.\, x$$

Where A = Area of individual rectangle
x = x − co-ordinate of rectangle's centroid
y = y − co-ordinate of rectangle's centroid

14.2.3 The bending moment distribution for the most severe loading case on the panel must then be calculated. At the position of maximum bending moment the stress distribution should be calculated using the unsymmetric bending theory. See Fig. 35.

Where $\bar{G}$ = Centroid of section
Mx = Applied bending moment on section about the x axis
σ_z = Unsymmetric bending in section
α = Position of neutral axis

$$\text{And} \quad \sigma_z = \frac{Mx}{Ix\,Iy - Ixy^2}\,(y \cdot Iy - x \cdot Ixy)$$

$$\tan \alpha = \frac{Ixy}{Iy}$$

It should be noted that these formulae only apply when the moment My is zero.

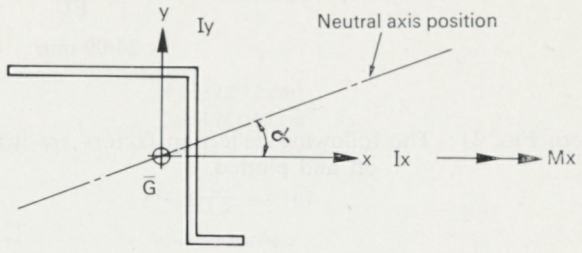


FIG. 35
Asymmetrical section showing co-ordinate system.

The local buckling stress of the flange and web should be checked, and the ends of the covers should also be checked to ensure that the shear loads can be taken by the webs.

The stress levels should be checked against the permissible stress levels in the Society's Rules.

The maximum deflection of the cover using unsymmetric bending theory should be compared with the permissible values in the Rules.

14.2.4 The 'ASYM' program

The Society has developed the program 'ASYM' for use with the Hewlett-Packard 9845s desk-top computer. The program carries out the unsymmetric calculations referred to in para 14.2.3 and has three main parts as follows:

(a) The first part enables the geometric properties of sections composed of rectangular or square elements to be computed. The elements may be horizontal, vertical or inclined and need not be symmetrical about any axis.

(b) The second part calculates the asymmetrical bending stresses at up to six points per run arising from an applied moment and plots the section. Examples of the output are shown in Figs. 36 and 37.

(c) The third part computes the optimum size of an additional horizontal or vertical element required to reduce the unsymmetrical bending stresses to a prescribed limit. Data checks are arranged after each block of input data. A full range of options are available to enable any of the parameters to be modified with the minimum of data re-entry and produce revised output for the amended requirements. Also included, for convenience, is an option which enables the buckling stresses for panels to be calculated without losing or changing any of the current data for the main program.

The program does not give the maximum deflection and this would still require to be calculated.

14.2.5 The shear centre

The foregoing calculations do not take account of the loads being applied away from the shear centre. Failure to apply the container loads at the shear centre could result in high stresses, large rotations and the greater possibility of buckling failure occuring. For this reason the shear centre of the section must be calculated, to ensure that the container loads are being applied as near as possible to the shear centre.

One practical means of removing this effect would be to share the container loads between two adjacent panels by arranging bridging pieces. These pieces would restrict the movement between the panels and should mean a reduction in scantlings as the load is being shared.

APPENDIX 2

COVERS WITH PANELS OF ASYMMETRICAL SECTION

Example of Desk- top Computer program output.

SECTION ACCORDING TO DATA INPUT

SECTION NO. 1.0

HATCH COVER (NO. 1 HATCH,ELEMENT 4)

ELEM	A	B	X	Y	C	D	Alpha	SHEAR
1	92.000	.950	46.000	61.700	0.000	0.000	0.000	
2	40.000	1.200	72.000	62.800	0.000	0.000	0.000	
3	12.000	1.200	91.400	60.600	0.000	0.000	0.000	
4	.700	43.000	92.000	38.500	0.000	0.000	0.000	*
5	5.000	5.000	92.000	14.500	0.000	0.000	0.000	
6	10.000	12.000	92.000	6.000	0.000	0.000	0.000	
7	5.300	8.000	89.000	56.000	0.000	0.000	0.000	*
TOTAL AREA =	367.300	78.071	37.831				OVER-ALL	

INA XX = 242759.7 Y lower -37.831 Y upper 25.569 63.400
MODULUS AT EXTREME FIBRES BELOW 6416.930 ABOVE 9494.340

INA YY = 202630.9 X left -78.071 X right 19.329 97.400
MODULUS AT EXTREME FIBRES LEFT 2595.481 RIGHT 10483.085

I 1 2 (NASTRAN) OR Ixy = -122440.4
ANGLE OF PRINCIPAL AXES = 40.347 DEGREES

INA UU 346768.8 RADIUS OF GYRATION 30.726
INA VV 98621.8 RADIUS OF GYRATION 16.386

(Sigma b*t3)/3 = 4666.500 (sum of individual elements)
SHEAR AREAS:- VERTICAL 72.500 HORIZONTAL 0.000

APPLIED MOMENT Mx 5707.000

ASYMMETRIC BENDING STRESSES ABOUT AXIS AT -31.143 DEGREES

POINT	X	Y	STRESS
1	0.000	62.150	-.773
2	92.000	63.350	1.148
3	97.400	61.200	1.185
4	87.000	0.000	-1.097
5	97.000	0.000	-.892
6	52.000	63.350	.330

FIG. 36

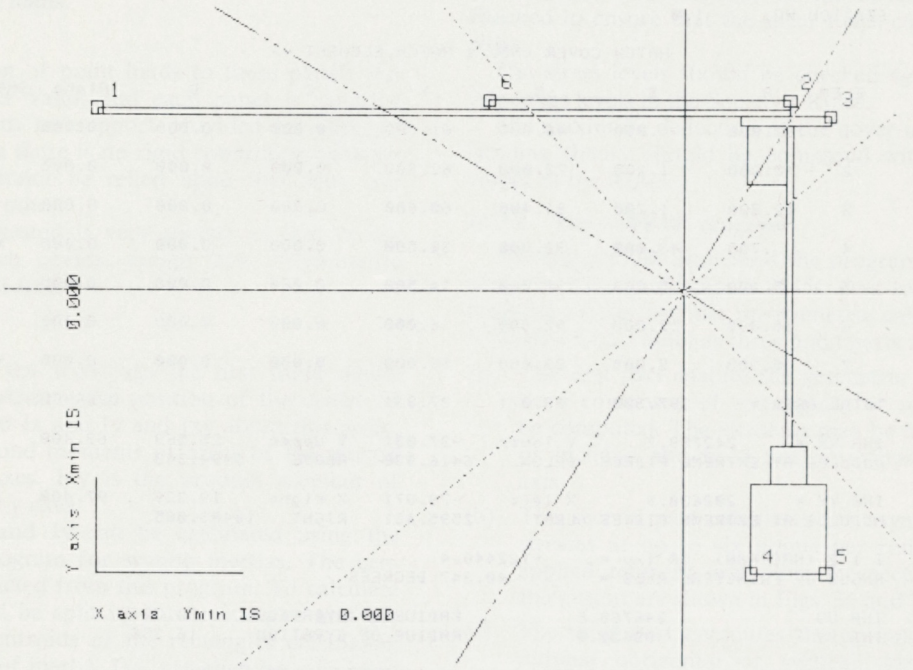
Example of desk top computer program output.

APPENDIX 2

COVERS WITH PANELS OF ASYMMETRICAL SECTION

Example of Desk - top Computer program output Contd.

SECTION ACCORDING TO DATA INPUT



SELECTION OF SUITABLE ADDITIONAL ELEMENTS TO SATISFY LIMITING STRESS

LIMITING STRESS 1.20 DIRECTION 2 POSITION 3
INITIAL BREADTH 6.00 BREADTH INCREMENT .500 MAXIMUM BREADTH 8.00
THICKNESS INCREMENT .100 MAXIMUM THICKNESS 5.300
ORIGIN X, Y 91.650 60.000

DIMENSIONS OF POSSIBLE ELEMENTS					STRESS POINTS				
A	B	X	Y	AREA	1	2	3	4	5

NO ADDITIONAL ELEMENT REQUIRED

FIG. 37

Example of desk top computer program output.

APPENDIX 3

15. DIRECT CALCULATION METHOD FOR STRENGTH AND STIFFNESS OF EDGE OF COVER OR PANEL.

15.1 Loading from heavy duty cleat

As an example, a uniformly loaded cover is considered having the following properties and spacing of cleats.

Inertia of cover edge	—	I	— 40,000 cm^4
Section modulus at edge	—	Z	— 2,000 cm^3
Youngs modulus for steel	—	E	— $2{\cdot}1 \times 10^6$ kgf/cm^2
Spacing of cleats	—	S	— 6 metres
Cleat failure load	—	W	— 20 tonnes

Assuming that edge of cover, acting as simply supported beam, bears the failure load of the cleat. The equivalent distributed load, w, would be,

$$w = \frac{W}{S} = \frac{20}{6} = 3{\cdot}333 \text{ tonnes f/metre}$$

The resulting bending moment, M, is,

$$M = 0{\cdot}125 \times 3{\cdot}333 \times 6^2 = 15{\cdot}0 \text{ tonnes metres}$$

The maximum stress, σ, will be,

$$\sigma = \frac{M}{Z} \times 10^5 = 750 \text{ kgf/cm}^2$$

15.2 Weathertightness

The stiffness of the edge is now examined considering only the reaction force of the rubber gasket. This would occur when an acceleration of 1.c.'g' affects the hatchcover and its loading and therefore the apparent weight of the cover and load becomes zero. The reaction of the rubber gasket will force up the hatch cover periphery at this time.

The compressive force of a rubber gasket is proportional to the amount of compression and for the purpose of this example is taken as 10·0 kgf/cm at 12 mm compression. Therefore, assuming that the edge is uniformly loaded as in 15.1 the maximum deflection, ù, will be,

$$\grave{u} = \frac{5 \text{ w(kgf/cm) } S^4 \times 10^8}{384 \text{ EI}} = \frac{0{\cdot}62 \text{ w } S^4}{I} \text{ cm} = 0{\cdot}201 \text{ cm}$$

$$= 2{\cdot}01 \text{ mm}$$

The residual amount of compression will be sufficient to maintain weathertightness.

For an actual case the cover designer should supply the gasket compressive force and the allowable compression.

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Lloyd's Register Technical Association

INDEX TO THE TRANSACTIONS

1920 — 1980

Compiled by

R. J. HOOK

RESULTANT HULL STRUCTURES

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LLOYD'S REGISTER TECHNICAL ASSOCIATION 1920—1980

SIXTY YEARS IN RETROSPECT AND PROSPECT

The year 1980 marks the sixtieth year of the Lloyd's Register Technical Association and can thus be regarded as the "diamond jubilee" year. To have steadily achieved and maintained the purpose for which it was formed at the inaugural meeting held on the 6th October, 1920 at the London Headquarters office can be regarded with satisfaction by all who have played a part in whatever capacity, in its affairs.

The presentation of this index covering the period 1920–1980 provides the opportunity to offer some information about the Association to those who may find it of interest and who perhaps have joined the Society since the previous index was printed in 1975.

The object of the Association, as stated in its constitution, is:

> "The advancement and dissemination of knowledge among its membership in respect of Shipbuilding, Marine Engineering and other subjects of technical interest by the preparation, discussion and circulation of technical papers".

To achieve this object has been and continues to be the task and challenge to the Association's Committee and membership.

How well this has been accomplished can be briefly seen by examination of the contents of this index. The high calibre of the papers presented over this period reflects with accuracy a remark made by the first President of the Association, Mr. W. Watt, at the inaugural meeting when he said:

"The formation of the Association commences another chapter in the long and honourable history of Lloyd's Register and I venture to think that in it we will write a chapter which will hold its own with any that have gone before".

Mr. Watt went on to comment about the need for specialisation within the Society and again the accuracy of his observations have become increasingly self evident with the passing years, and is reflected in the title and content of many papers presented to the Association. A good number of the papers have been of direct help to Surveyors in the course of their duties world wide and in this way the Association provides a most useful service to its members.

The object of the Technical Association is achieved by the presentation and discussion of papers written by its members and invited authors. During the years 1920-1970 it was known as Lloyd's Register Staff Association, but was renamed in 1970 to avoid confusion with a new organization formed to perform a function within the Society in conjunction with Management concerning staff interests.

The Technical Association plays no part in any official business of Lloyd's Register of Shipping and its operation and direction from Headquarters are matters of convenience for administrative reasons. That it has been well served by a number of honorary committees for sixty years is self evident as the contents of this index briefly indicate. Three hundred and six papers have been presented during the period 1920-1980 and it can be fairly claimed that for technical merit and variety of interest and subject matter, together with the extent of practical knowledge reflecting experience world wide, the Technical Association transactions can stand proudly in comparison with the annals of any learned society or professional institution.

The transactions reflect various technological developments in the many fields covered by the Society's activities during the past sixty years, and from examination of some earlier papers it can be seen that they are gradually acquiring some value as historical records.

In addition to what is hoped will be a useful reference, the index also provides a means of bringing the names of some of our respected predecessors to the attention of succeeding generations of members who, in the nature of things, come and go on the tides of time. In this way it is hoped members will feel that some worthwhile continuity is found and handed on.

The transactions are not only a means of storing experience and traditions of the past but are also a means of disseminating knowledge of present practice. Examination of papers over the years indicate that this has always been the case and that it continues to be so may be regarded as a re-assuring sign for the future.

The present era is one of technological advance and development with the emphasis on intensity and increasing diversity in those fields within which the Society's affairs have their place, and this in turn provides opportunity and challenge to the Technical Association.

There is certainly as much need now for papers on a variety of subjects both general and specialist as there has ever been during the past sixty years and perhaps more opportunity than hitherto, having regard to the increasingly diverse technological activities with which the Society is concerned. It is hoped therefore that in addition to providing what may be found to be a useful reference, the index to the transactions will provide some stimulation and guide to subjects which may be usefully dealt with in the future. Many papers, found helpful in the past and relevant to present practices and subjects, could be brought up to date with advantage to the present technical staff. The presentation of papers dealing with specialist subjects has always been a feature of the Technical Association and remains so. It was said in 1920 that the field was large and the subjects numberless. Sixty years later, in 1980, that comment is clearly even more applicable.

These notes provide the opportunity of drawing members attention to the generosity and support of the General Committee of Lloyd's Register of Shipping, without which the Technical Association could not have functioned for sixty years and reached its "diamond jubilee". It is felt that all members would wish to express their appreciation of the General Committee's interest and assistance in this connection.

Appreciation must also be expressed to the Printing House staff who over the years have played their part in the Association's affairs, often under pressure of work and sometimes in adverse circumstances, to ensure that the papers are printed.

Finally it is desired to express grateful thanks to Mrs R. J. Hook for her assistance with the preparation of this index.

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